PB-218 259

WASTE STABILIZATION LAGOONS

Public Health Service
Washington, D.C.

August 1961

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 218 259

WASTE STABILIZATION LAGOONS

Proceedings of a Symposium
at Kansas City, Missouri
August 1-5, 1960

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

172

WASTE
STABILIZATION
LAGOONS

A Review of Research and Experience in Design, Construction, Operation and Maintenance

Details of illustrations in
this document may be better
studied on microfiche

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control
Washington 25, D.C.

I

The Symposium was arranged and conducted by the Public Health Service at the request of-
Missouri Basin Engineering Health Council

This publication of the symposium proceedings was prepared by the staff of the Division of Water Supply and Pollution Control, Region VI, Public Health Service, U.S. Department of Health, Education, and Welfare, Kansas City, Mo.

Public Health Service Publication No. 872
August 1961

This Symposium

was Sponsored by the

MISSOURI BASIN ENGINEERING HEALTH COUNCIL

Albert W. Happy, Jr., Chairman

COLORADO

William N. Gahr, Director
Division of Sanitation
State Department of Public Health

IOWA

Paul J. Houser, Director
Division of Public Health Engineering
State Department of Health

KANSAS

Dwight F. Metzler, Director
Division of Sanitation
State Board of Health

MINNESOTA

Frank L. Woodward, Director
Division of Environmental Sanitation
State Department of Health

MISSOURI

Albert W. Happy, Jr., Director
Section of Consultant Services
Division of Health

MONTANA

C. W. Brinck, Director
Division of Environmental Sanitation
State Board of Health

NEBRASKA

T. A. Filipi, Director
Division of Sanitation
State Department of Health

NORTH DAKOTA

W. Van Heuvelen
Executive Officer
State Department of Health

SOUTH DAKOTA

Charles E. Carl, Director
Division of Sanitary Engineering
State Department of Health

WYOMING

Arthur E. Williamson, Director
Division of Environmental Sanitation
State Department of Public Health

CONTENTS

Page

MISSOURI BASIN ENGINEERING COUNCIL iii

FOREWORD vii

WELCOME 1
Lewis H. Hoyle, M.D.

HISTORY OF RAW SEWAGE LAGOONS IN THE MIDWEST 2
Jerome H. Svore

HISTORY OF OXIDATION PONDS IN THE SOUTHWEST 7
David F. Smallhorst

LAGOON RESEARCH PROJECT OF THE PUBLIC HEALTH SERVICE AT FAYETTE, MISSOURI 15
Herbert C. Clare

RESEARCH AND INSTALLATION EXPERIENCES IN CALIFORNIA 33
William J. Oswald

VIRGINIA'S EXPERIMENTAL INSTALLATION 41
C. E. Cooley and R. R. Jennings

SEWAGE LAGOONS IN AUSTRALIA 53
C. D. Parker

ECONOMICS OF WASTE STABILIZATION LAGOONS IN REGION VI 57
Herbert C. Clare and Daniel J. Weiner

USE OF STABILIZATION PONDS IN THE UNITED STATES 68
W. W. Towne and W. B. Horning, III

MISSOURI BASIN CRITERIA 75
Glen J. Hopkins

LAGOON TREATMENT OF MEAT PACKING PLANT WASTES 82
F. W. Sollo

LAGOON DEVELOPMENT AND ACCEPTANCE IN MISSISSIPPI 89
J. E. Johnston

EXPERIENCES IN CANADA 95
H. L. Hogge

SEWAGE LAGOONS AND MOSQUITO PROBLEMS 101
Leslie D. Beadle

LAGOON DISPOSAL OF LIVESTOCK WASTES 105
Ralph L. Ricketts

Page

OPERATING EXPERIENCES IN THE TEN MISSOURI BASIN STATES:

North Dakota 109
W. Van Heuvelen

Montana 112
Claiborne W. Brinck

Minnesota 116
Harvey G. Rogers

South Dakota 118
Donald C. Kalda

Iowa 133
R. J. Schliekelman

Kansas 136
Russell Culp

Missouri 140
Jack K. Smith

Nebraska 144
T. A. Filipi

Colorado 147
Ronald C. McLaughlin

Wyoming 151
David Green

ARCTIC SEWAGE LAGOONS 155
Charles F. Walters

IMPROMPTU REMARKS BY JOE WILLIAMSON, JR. 159

CRITIQUE 161
C. H. Atkins

BIBLIOGRAPHY OF WASTE STABILIZATION LAGOONS 165

FOREWORD

Use of waste stabilization lagoons for treating raw sewage and certain industrial wastes has become very popular in the Missouri Basin States. Since early 1957, the Public Health Service, in cooperation with the City of Fayette and the Division of Health of Missouri (and subsequently, the Missouri Water Pollution Board) has operated a research installation at Fayette, Missouri. In 1959, the Missouri Basin Engineering Health Council, (the Chief Sanitary Engineers of each of the 10 Missouri Basin States) documented the design, construction and operating practices generally used for the several hundred installations then existing in the Missouri Basin.

Recognizing the widespread and popular interest in this economical method of waste disposal, the Missouri Basin Engineering Health Council requested that Public Health Service Region VI plan and conduct a symposium on waste stabilization lagoons under sponsorship of the Council.

Capitalizing upon the central location of the lower Missouri River Basin, the numerous installations in the Kansas City metropolitan area available for inspection and observation, the Fayette research facility, and the full cooperation of the official health and water pollution control agencies of the 10 Basin States, the symposium was designed as an intensive review of research and experiences in the design, construction, operation and maintenance of waste stabilization lagoons.

Registration of 330 persons, from 32 States and 7 foreign countries, demonstrates the widespread interest in this subject. It was indeed a pleasure for Public Health Service Region VI to arrange and conduct the symposium, and we gratefully acknowledge the full cooperation of the Basin States and the Robert A. Taft Sanitary Engineering Center. Appreciation is also expressed to the program participants, all serving without compensation of any kind, who in the final analysis are truly responsible for the success of the symposium.

It is hoped that the Proceedings of the Symposium will be helpful to the many persons interested in the application of waste stabilization lagoons for treatment of sewage or industrial wastes.

GLEN J. HOPKINS
Regional Engineer
Public Health Service Region VI

WELCOME

Lewis H. Hoyle, M. D.*

It is a real pleasure for me to welcome you this morning and to "kick off" the first Symposium ever devoted to sewage lagoons. A pleasure for several reasons:

First, this is a symposium sponsored by the State Sanitary Engineers of the 10 States of the Missouri River Basin and conducted by the Public Health Service at the request of the 10 States. This is a fine example of a close working relationship of the State and Federal agencies.

Secondly, the current popularity and widespread use of raw sewage lagoons had its start in, and received its momentum from, Public Health Service Region VI, and I am pleased that members of my own staff have made important contributions to this movement.

This Regional Office first had opportunity to observe raw sewage lagoons in the State of North Dakota through the early work and interest of Jerry Svore and Willis Van Heuvelen. While we now know that several installations preceded those in North Dakota, most, if not all ponds were used for supplemental treatment; not raw sewage. Jerry and Van, as a team, were the first to develop design standards and to actively promote raw sewage lagoons, with full and unqualified endorsement of the State Health Department.

Their enthusiasm was soon absorbed by Glen Hopkins, who became the first champion of the cause among Public Health Service officers. His early endorsement of heavier loadings and lesser isolation than used in the Dakotas, to facilitate use of lagoons in more densely populated areas, caused some concern among Public Health Service engineers and in some State Health Departments. Dr. Neel's evaluations of early installations in the Kansas City area gave impetus to the movement. The plea of Regional Office for investigations, research and demonstration projects by the Service seemed to fall upon unsympathetic ears. Fortunately, however, Wally Towne also became convinced - and the Public Health Service did undertake some modest projects: an evaluation of certain installations in the Dakotas; the Fayette project, for which you will receive the first report today; and some similar work at a penitentiary in Ohio which has not yet been reported.

This seems a minor effort, and it is regreted that the Public Health Service could not have undertaken these efforts earlier and more extensively. Surely they would have enhanced the promotional efforts that have led to the hundreds of installations we now have. When we consider that the interest started about 1950, the several hundred existing installations constitutes amazing progress.

We in Region VI are confident that in the future raw sewage lagoons will play an even greater role in lessening the costs of safeguarding the sanitary quality of our water resources. My staff have convinced me that lagoons have saved communities in Region VI more than they have gained from Federal Grants. We hope to share our experiences with other parts of the country. We hope this symposium will spread to other areas of the country the enthusiasm you note here. If it does this, the symposium will indeed be worthwhile.

I am happy to see the excellent turn out - I understand we have 318 people registered representing 32 states, all Regional Offices of the Public Health Service, and 7 foreign countries. What started as a Regional Symposium has turned out to be an international conference. Much of the experience and competency in this field is represented here today.

It is a real pleasure to welcome you here. The agenda indicates you will be quite busy the next five days, but I'm confident it will be a pleasant and profitable experience for you.

---

*Regional Medical Director, Public Health Service Region VI, Kansas City, Missouri.

HISTORY OF RAW SEWAGE LAGOONS IN THE MIDWEST

JEROME H. SVORE*

Before delving into the history of sewage lagoons, it might be well to briefly define what is meant by the term lagoon as used in this discussion. Various names have been applied to an open pond which receives sewage, such as stabilization lagoons, stabilization ponds, oxidation ponds and lagoons. In this instance, we are discussing a pond of engineering design which is constructed for the purpose of receiving raw sewage. It is further assumed that oxidation ponds are considered to be those ponds that are designed for the purpose of receiving, at least, primarily settled sewage. This may be from an ordinary sewage treatment plant, imhoff tank, septic tank and the like. Sewage lagoons, however, receive raw sewage from a municipality including incidental industrial wastes.

During the mid-twenties, cities in California, Texas, North Dakota and probably other states, used lagoons as a means of treating municipal sewage, however, in each case it seemed to be more by accident than design. It was during this period that a student at the University of Texas made a survey for the State Department of Health in order to ascertain why the sewage from the town of Palestine, which was discharging into a small, swampy area, was converted to a fresh, sparkling stream after a few miles. Shortly after this survey was made, Vic Ehlers, then State Sanitary Engineer for Texas, was held, so to speak, in mild ridicule when he suggested during a National engineering meeting that aquatic plants probably played an important part in the oxidation of this sewage. It was a short while later that Mr. Ehlers recommended to the city of Abilene that they pond their sewage by the construction of a small dam until such time as a sewage treatment plant could be built. This lagoon functioned successfully for many years. During the mid-thirties, Texas A & M College became interested in the operations at Abilene and constructed a 14-acre pond at the College to carry on some limited investigations of lagoon operation.

In 1924, Santa Rosa, California, in an attempt to escape the cost of a sewage treatment plant, uncovered gravel beds which the city council thought could be used as natural filters prior to discharging city sewage into the then highly polluted Santa Rosa Creek. Raw sewage was discharged on to the exposed gravel which shortly became sealed resulting in an impoundment of sewage to a depth of about three feet. Fortunately for the city, however, the experiment was not a failure and the overflowing effluent from the pond resembled an effluent from a trickling filter. It had no odor and was easily disinfected. Also in 1924, the town of Vacaville, California, being faced with a sewage disposal problem, used a dry gulley as an impounding reservoir for releases of sewage during the winter months only. Here again it was found that the impounded sewage underwent characteristic changes through BOD reduction with an increase of dissolved oxygen and in some cases nitrogen was found to be present.

The first lagoon of record in North Dakota was in the town of Fessenden and was placed in operation during 1928. This community had no nearby stream to handle the effluent from the new sewage system completed during that year so they decided to empty their sewage into a pothole about a mile and a half from the town hoping that the distance would be adequate to prevent any odor or nuisance problem. This natural lagoon is still in operation 32 years later and the city has experienced no odor or nuisance problems. It was the success of this enterprise that gave engineers some degree of confidence that a raw sewage lagoon could be designed, placed in operation and function successfully considerably closer to a city.

---

*Regional Program Director, Water Supply & Pollution Control, Public Health Service, Dallas, Texas (former North Dakota State Sanitary Engineer).

Although there is much information in the literature on various types and designs of ponds used for sewage disposal here and abroad, indications are that the modern-day lagoon built on good, sound engineering principles under modern concepts of treating raw sewage was first placed in operation in 1948 in Maddock, North Dakota. Prior to this time, there had been no real recognition on the part of any official agency that a raw sewage lagoon was an acceptable, reputable method of handling sewage, although oxidation ponds had been accepted as a means of handling the effluent from a primary plant. In fact, the State of Texas had some 200 installations of this type, but it seems that no engineer had purposely proceeded to design a pond to handle raw sewage on a permanent basis.

Credit should be given at this point to Mr. L. W. Burdick of the engineering firm of Lium and Burdick who is responsible for this initial design.

Maddock is a town of approximately 1,000 people and it was felt that a lagoon of 10 acres would be needed. This initial design, with a maximum depth of five feet, proved to be adequate from a treatment standpoint, and a high degree of BOD reduction was found at any point 50 feet or more from the influent line which was located at the center of the pond. Because the lagoon is in a pothole area, however, it was found necessary to expand its size as seepage and evaporation were not adequate to dispose of the entire sewage flow. A second and third cell was added two years later. Sewage now flows in series through the three ponds providing adequate area for seepage and evaporation to obviate the necessity of a discharge to a water course. The second and third ponds also provide additional treatment but the basic treatment occurs in the first cell.

The success of this installation brought about considerable enthusiasm on the part of the North Dakota State Health Department engineers and they became active promoters of this method of treatment shortly thereafter. Several towns constructed lagoons during the following year, including the towns of Portland, Grenora, Butte, Hope and New Town. The rate of construction increased considerably during the following years and to date over 100 communities have raw sewage lagoons as their means of treating municipal sewage. This approximates two-thirds of the sewered municipalities in the entire state.

It is only fair to mention that during the initial introduction of lagoons into the Dakotas, the State Health Department engineers were subject to some ridicule. One enterprising city editor wrote an editorial of some literary accomplishment depicting the youth of the community skating in the moonlight on the beautiful lagoon with an occasional individual falling through the ice with somewhat disastrous results.

A few city councils throughout the state enthusiastically supported the idea of a sewage lagoon almost from the beginning and saw them as the economic solution to their money problems. In some instances, a community was able to construct a sewage system where prior to this time it had been impossible because of the high cost of a conventional sewage treatment plant. Nevertheless, State Health Department engineers felt that universal support throughout the state would never be fully recognized until lagoons could be upgraded in the eyes of competent engineers and agencies outside of the state.

In 1951 Glen Hopkins, Engineer-In-Charge of Public Health Service Water Pollution activities in the Missouri Basin, was invited to North Dakota to make a personal inspection of lagoons then in operation. It should be said that he was a "gone gooner" from the start and has been an enthusiastic supporter ever since. It was still not enough, of course, that the Basin Office in Kansas City favored this method of sewage treatment, and it was felt that what was really needed was an extensive investigation of the lagoons that were then in operation. Although support for such a project was almost immediate from Wally Towne, Engineer-In-Charge of Field Investigations at the Sanitary Engineering Center in Cincinnati as well as others, it was nearly three years before funds were made available to actually get the work under way.

In the meantime, other agencies of government had become interested in lagoons. The

Corps of Engineers, building a 20 million acre-foot reservoir on the main stem of the Missouri River in North Dakota, had a mammoth relocation job ahead of them. Much of the land to be flooded was within the Fort Berthhold Indian Reservation. Schools had to be relocated as well as small communities, and the construction of some sewage disposal facilities became the responsibility of the Corps. The District Office of the Corps of Engineers at Garrison was enthusiastic about the State Health Department's recommendations to build lagoons at these relocated sites. Here again, the Basin Engineer of the Public Health Service in Kansas City was called upon to obtain approval at higher levels within the Corps. Subsequently, this approval was obtained and these federal installations were numbered amongst the first lagoons to be built in the state. A few years later, the combined influence of the State Health Department, the Basin Office of the Public Health Service, and the Corps of Engineers personnel at Garrison was again brought to bear in connection with the construction of two Strategic Air Command bases at Grand Forks and Minot, North Dakota. This was the first use of raw lagoons by the Air Force and some of the top ranking engineers at the Washington level took a rather dim view of the Health Department's proposal. Nevertheless, with the State Health Department being insistent on this type of construction and with the complete approval of the Public Health Service Basin Office, the Air Force abandoned its original proposal of activated sludge plants.

The reason back of the State Health Department attitude in this matter may be of interest. The average military installation, such as one of the Strategic Air Command bases, operates on daily cycles of high and low water use. This is not conducive to high efficiency of operation in the normal type of sewage treatment plant. On the other hand, "slugging" a raw sewage lagoon with high volumes for a short period of time, does not affect its operation. More important than this, however, was the fact that both of these installations were to be located in areas where only dry-run creeks were available for final disposal of sewage. A lagoon could be designed in such a way that no final disposal was necessary over and beyond seepage and evaporation. Although outlet structures were provided, it was not anticipated that they would be used. On the other hand, should they ever be used, the lagoon size was such, and the treatment of such adequacy, that an intermittent effluent would in no way cause an obnoxious condition.

South Dakota was quick to follow the footsteps of its sister state to the north and even called on North Dakota to provide the site on which to construct the lagoon serving one of its communities. Lemmon, South Dakota purchased land across the state line on which their lagoon was built.

By the year 1955, there was little, if any, controversy in either of the Dakotas in regard to the use of sewage lagoons, except in a few isolated cases. By that time, there were nearly 100 lagoons in the Missouri Basin States, and they were already being designed for use in the Pacific Northwest.

The State of Missouri did not consider the use of lagoons until after one of their engineers had visited North Dakota in the fall of 1953 to observe installations then in operation. The enthusiasm of this engineer, Jack Smith, upon his return to Missouri, resulted in some of the consulting engineering firms starting work on them immediately. Within a year several were under construction in various parts of the state. The Missouri State Health Department, along with the County and City Engineers, recommended the use of lagoons as interim facilities for subdivision development pending the installation of interceptor and trunk sewers. Some of the first installations of this type were made in late 1954 and 1955. The local residents, however, in many instances, objected to having a sewage lagoon near their home, even on a temporary basis, and consistently brought their objections before the zoning boards. The development of lagoons gave some of these local interests new grounds on which to oppose zoning. They claimed the lagoons were too new, unproved, experimental, open ponds of sewage conducive to fly and mosquito breeding, odor, etc. Nevertheless, the boards continued to grant applications and within a short time there were numerous lagoons installed in the subdivision areas of Jackson County, Missouri, which is part of the Kansas City metropolitan area.

Kansas accepted sewage lagoons at a much later date. The first installations in the Kansas portion of the Kansas City metropolitan area was the Mission Township installation. The zoning hearing on this installation was during December 1955, and they requested testimony from Mr. W. Van Heuvelen, Chief of the Water Pollution Control Program in the State of North Dakota. As usual, the opposition considered lagoons to be untried and of an experimental nature, and, therefore, insisted that the installation should not be made. Nevertheless, the lagoon was installed on a temporary basis and operated successfully. Within the last two or three years, Kansas has openly accepted lagoons for the treatment of raw sewage as a proven installation and they no longer require a minimum of primary treatment ahead of the lagoon.

Although the Pacific Northwest can hardly be considered to have a part in the history of lagoons in the Midwest, brief mention of their spread westward might be in order. Vale, Oregon was the first city in that part of the country to inquire of their consulting engineers as to the feasibility of using a lagoon to treat sewage from their community. Fortunately they had employed the firm of Clark and Groff of Salem, Oregon, former North Dakota engineers of the pre-lagoon era who had kept themselves informed of progress being made in the use of lagoons. As a result, Vale became the pioneering city in the Pacific Northwest with the first modern-day engineered lagoon as their treatment facility.

Other engineers of this area were quick to follow with their own variations in design. It seemed to be very difficult for the average consultant to divorce his thinking from the old tried and true method of sewage treatment, namely, first removing settleable solids. It seemed logical, therefore, to have a small primary pond to catch the solids. Some were built this way, which of course, resulted in an anaerobic primary cell. Such a lagoon was built at Long Beach, Washington and provided excellent research facilities for the State Health Department, Pollution Control Board, and the Public Health Service Portland Office. Despite the under-design, the anaerobic condition, an effluent filter that did not function, and a population that varied from 700 in the winter to 7,000 on a summer weekend, there were no complaints.

It was quite obvious after the first year's operation, however, that a single cell would have performed better, been simpler to construct, and cost considerably less. A similar design in another location may not have been as satisfactory. Although this was a high-rainfall area with little sunlight, a continual onshore breeze allowed homes to be constructed 150 feet to the west of the lagoon.

Another pioneering design that should be mentioned in passing was also for a Washington city. The consulting engineer proposed a circular lagoon with dykes running like spokes of a wheel to a central lagoon. Here again, was the old principle of primary settling. The writer recommended removing all internal dykes and building the lagoon as one large cell.

During the latter part of 1954, the Public Health Service had secured adequate research funds to start limited field investigations in the Dakotas. William Davis, out of Wally Towne's office at the Sanitary Engineering Center in Cincinnati, arrived in Bismarck early in 1955. During the next year and a half, he conducted an extensive field investigation of three lagoons in South Dakota and three in North Dakota. A final report published in 1957 indicated the success of sewage lagoons even though some of those studied were not built in accordance with accepted design. The report, nevertheless, did bring about a degree of respectability that this type of facility had not previously enjoyed. It also substantiated the fact that the basic criteria originally adopted for design seemed to be quite well justified.

During this same period, the Public Health Service further backed their interest in lagoon research by constructing a group of ponds at Lebanon, Ohio near the Sanitary Engineering Center, and established an additional research project in connection with an experimental lagoon at Fayette, Missouri. The results of this experimental work had considerable influence on their adoption in the Lower Missouri Basin.

The State Sanitary Engineers of the Missouri Basin States continued their pioneering by promulgating the first set of design standards to be adopted by more than one state. At this point, it seems, lagoons finally became of age and could be spoken of with dignity in proper circles. It is interesting to note that these recommended design criteria in no way deviated from the basic concept of design originally developed by Roy Burdick for the Maddock lagoon back in 1948.

Other states in the midwest were quick to see the advantage of raw sewage lagoons although not mentioned in this narration. Montana had units in operation shortly after the first North Dakota lagoons were built. The Chief Engineer of the Provincial Health Department of Sask, Canada was an early visitor to Dakota installations and was one of the first to recommend the use of this method of treatment for Regina, Sask., a city of nearly 100,000 population. Oklahoma too, first took advantage of raw lagoons during the early fifties with the State Health Department engineers approving the first set of plans submitted in conformance with modern design criteria. Wyoming and Colorado, whose Chief Sanitary Engineers had first-hand experience with early North Dakota lagoons, carried their enthusiasm with them when they took over their present responsibilities.

It is too much of a temptation in relating the history of lagoons in the midwest, not to tell the story of sewage treatment facilities in Minot, North Dakota. It is certainly a commendation for raw sewage lagoons. This city of nearly 30,000 population completed a modern treatment plant, complete with filters, final clarification, recirculation and vacuum sludge drying during the early fifties. In fact, it was the last sewage treatment plant built in the state. Because of the lack of funds, parallel units were not constructed but in order to insure construction within a five-year period, when anticipated expansion was thought to be necessary, duplicate equipment was purchased at the request of the State Health Department. The city postponed further action even after the five-year period, trying to determine whether to expand the present plant, using equipment already purchased, or to abandon this modern facility and start over with a lagoon at a new site. The decision was made recently in favor of the latter. The long range economics of the situation, taking into consideration the cost of operation and maintenance and the effect of the effluent on the Mouse River weighed heavily in favor of a lagoon despite the abandonment of a modern plant that cost the city over $600,000. Mr. Van Heuvelen's comment on this was that they got caught between model changes. This frequently happens also when you buy a new car.

It would be difficult to determine accurately the number of installations now operating in the United States that are designed essentially along the lines of that first installation in Maddock back in the last forties. No doubt the number built during the last ten years numbers in the hundreds. There have been many and varied designs where the consulting engineer felt that he could improve on the basic simplicity of the originally designed lagoon at Maddock, North Dakota. It is questionable at this date, however, that building a more complicated lagoon has in any way improved its effectiveness as a sewage treatment facility.

Maybe the honor of having the first sewage lagoon, or at least the first pond to receive sewage should go to the city of San Antonio, Texas, where sewage was ponded at the turn of the century. The city at that time contracted with R. H. Russel, J. A. Simons and Associates "for the construction of a ditch, dam, and reservoir on Mitchell Lake for the proper disposal of sewage of the city of San Antonio." Most early Texas installations utilized sewage holding ponds primarily for broad irrigation but nevertheless, this was pioneering and led the way to later applications. Certainly the consulting engineers, municipal officials, and the State Health Department engineers in North Dakota and other midwestern states have their little place in history for the emphasis they gave to this effective means of treating sewage.

THE HISTORY OF OXIDATION PONDS IN THE SOUTHWEST

D. E. SMALLHORST*

The title of this presentation is such as to invite considerable reference to the State of Texas; consequently, it is trusted the following comments will be received in the spirit of a historical review which may or may not be firmly documented in the journals of our profession and not as another "Texas brag". Truly, the evolution of present day oxidation pond sewage treatment devices does have certain roots which originated in Texas as far back as the turn of this century. A brief resume of this background is submitted here to substantiate this statement.

Any claim to fame the State of Texas might make for pioneering the use of oxidation ponds in the field of sewage treatment can probably be attributed to two major influences. The principal influence is undoubtedly the arid nature of a large portion of the State, which leads the citizens of that area to have a very high regard and respect for water. What is considered a legitimate water use in some sections of the nation is looked upon as an illegitimate water abuse in this area. The average annual rainfall across Texas varies from less than 10 inches at El Paso on the West to about 50 inches at Texarkana on the East. It is hardly astonishing then, that under these circumstances it becomes almost second nature for Texans to attempt to make full use of all available water supplies. This tendency is reflected in history wherein the sewage from the City of San Antonio was utilized on the City Hay Farm as early as 1901. The second major influence in Texas' early development and use of oxidation ponds is undoubtedly the result of the visionary genius and insatiable inquisitiveness of one V. M. Ehlers, State Sanitary Engineer of the Health Department for some 44 years, from 1915 to 1959. The very nature of this gentleman was such as to instill in others the desire to search for answers of the many unknowns which would contribute to a more healthful environment. Very important, also, was his emphasis upon economy-getting the cost down where it would be within reach of individual citizens of smaller communities. It was through his efforts that many of the early oxidation pond, or pond-irrigation, projects were initiated. Mr. Ehlers also sponsored many of the early basic studies on oxidation pond performance which served as a starting point for the establishment of design criteria when the big boom in oxidation pond construction started in the early 1940's (during World War II).

The development of sewage lagoons, as they were called in Texas during the early days, is primarily the result of the outgrowth of the practice of land disposal of sewage effluent in that vast area of deficient rainfall for irrigation water. As previously inferred, the City of San Antonio went into the sewage lagoon-irrigation business in the first decade of this century. The artificial impoundment involved in this operation became known as Mitchell Lake, which is still in use and is comprised of some 680 acres of surface area with a maximum depth of about 12 feet, averaging, however, 4 to 5 feet in depth. Admittedly, it was constructed as a holding pond in order to permit more efficient use of water for irrigation, but algae began oxidizing the sewage in the lake, thus constituting probably the first and certainly the largest oxidation pond in this country. During the third decade, in 1925 to be more specific, a lagoon-irrigation arrangement was set up by the City of Abilene which served the City until the advent of Public Law 660 when more refinements were added but land disposal is still being utilized. A great deal of basic data was obtained from the experimental pond built at Texas A & M College in 1929, while in 1936 the City of Kingsville installation was constructed, receiving all of the sewage from the City of Kingsville and serving as an irrigation water source for agricultural experimentation on the famous King Ranch. Considerable research was conducted on this pond by Texas A & I College of Kingsville.

---

*Director Water Pollution Control Division, Texas State Department of Health, Austin, Texas.

As we recall, it was the results of the studies made on these early installations that influenced Mr. Ehlers and his co-workers to conclude that some type of primary treatment was highly desirable ahead of impoundments in order to adequately dispose of solids, floating material, control public health hazards, and reduce odors. This policy is still being continued to date, altho recent developments and research results appear to contradict their original conclusions. To learn more about this aspect of pond operation is the main reason for our attendance at this symposium; but to return to our historical review.

In the early stages of World War II, rapid and unpredictable population increases at military installations as well as at neighboring municipalities brought about the construction of numerous oxidation ponds to cope with the resultant overloads upon existing facilities. The fact that this type of construction could be accomplished fast, cheap, and with a minimum use of critical material made them especially attractive. Consequently, by the end of the war, Texas had acquired quite a number of oxidation pond installations which afforded an excellent opportunity for conducting performance studies and planned observations. This opportunity was further capitalized upon as engineering and technical personnel of the Department returned from the Services and the staff began to assume its peacetime stature. A summary of these studies is recorded in Chapter XIII of the 2nd Edition of the "Manual for Sewage Plant Operators" written, edited, published, and sold by the Texas Water and Sewage Works Association. This publication came out late in 1950 or early in 1951 and coincidentally other works on oxidation ponds began to appear in technical publications. During the period from 1950 to about 1955, oxidation ponds were a very popular subject of discussion between engineers and technicians of neighboring as well as more remote States, and during this time several States in the Southwest tried a few ponds "on for size". At the present time according to figures obtained in a very recent survey of five States in Region VII there are a total of 274 ponds in operation. Further reference will be made regarding this survey later in this paper. With regard to the State of Texas however, from 1946 to date there has been a gradual and orderly formulation of policies by the Texas Health Department as to the use and application of oxidation ponds. There are now some 700 sewage treatment plants in Texas and of these about 200 have oxidation ponds or "lagoons" in one form or another. Most of these utilize the ponds as a means of secondary treatment, with the ponds being the flow-through type and the effluent being discharge to a water course or employed for irrigation. In this predominately water scarce area, it is not exactly surprising, therefore, that the utilization of effluent on land has resulted in several law suits by downstream riparian landowners claiming rights to the use of this water and insisting it be placed in the stream.

Although it is rather difficult to describe a "typical" oxidation pond installation, most of the Texas plants follow a rather routine pattern quite similar to those in other areas; however, there are four rather novel applications worthy of mention for general interest. The City of Austin has recently constructed ponds to treat excess activated sludge and digester overflow. Approximately 275,000 gpd of waste activated sludge with a BOD of about 4,500 ppm plus about 15,000 gpd of digester overflow with a BOD of about 300 ppm, are pumped into three ponds which can be operated in series or parallel. These ponds are 85, 65, and 41 acres in size. River water is added at a rate varying from 2,500 to 10,000 gpm chiefly for the purpose of maintaining a constant water level in the ponds. About 7 MGD of effluent with a BOD of less than 20 ppm is returned to the river.

So much for the application of oxidation ponds to the treatment of domestic sewage. The use of ponds in the treatment of industrial waste is also encouraging as well as interesting. Of course, in Texas, ponds have been applied rather extensively to rural type of slaughter houses, poultry dressing plants, milk processing plants, and even washateria wastes. These are usually preceded by septic tanks of one sort or another. In more recent years the adaptation of pond treatment to larger and more complex industries has been quite gratifying. Probably the first large-scale installation was at a cotton seed oil processing plant to treat the process waste by the use of some 15 ponds constructed on the contours of an 85 acre hillside. The first pond served as a receiving pond and from there the flow was split to 14 ponds operating in series-parallel. The raw waste had a BOD of about 3,000 ppm whereas the waste in the last pond had 100 ppm BOD or less. Because of evaporation and seepage losses there is ordinarily no effluent, but in the event there were, it would probably be of satisfactory quality. Odor problems were quite serious at this installation for about the first 18 months of operation, then apparently the proper strain or organism "took over" and no further difficulties have been experienced. The City of Weslaco operates 32 acres of oxidation ponds specifically designed to treat canning plant wastes ranging from peas to pineapples. The ponds are located adjacent to the domestic sewage treatment plant, which is of the two stage high-rate trickling filter variety. Two ponds, sixteen acres each, are designed to operate in series, treating some 300,000 gallons of food processing wastes per day. Initially, sodium nitrate was added to supply nitrogen and reduce the BOD loading, which, dependent upon operations in the collector system, varied greatly, as reflected in discharges of can cooling water with a BOD around 20 ppm while spillage from can fillers or reamer operations have a BOD of some 50,000 ppm. The average BOD of the mixture was considered to be about 750 ppm. The initial operation was not successful, partly due to abuse of the waste collection system by discharge of such materials as grapefruit rinds, whole carrots, whole tomatoes, silt, etc., and even when this abuse was abated, operation was still not entirely successful. It was decided then to add effluent from the domestic sewage plant to the industrial waste ponds. This was done since the effluent was known to be rich in nitrogen and also contained available dissolved oxygen which could be utilized directly. Possibly the most valuable contribution was biological seed material of an aerobic type. Effluent is now added at a rate of about 400 gpm and the combined discharge of domestic and industrial wastes from the ponds has an average BOD of 8.0 ppm and a dissolved oxygen content of 2.0 ppm. The process has operated in a satisfactory manner for five years. A petrochemical plant in East Texas has successfully applied pond action to the treatment of its wastes. A series of ponds totaling 62.6 acres is utilized. The raw waste is deficient in several respects and consequently, nutrients, such as nitrogen and phosphorous are added. Studies made by the company revealed that the waste was also deficient in certain basic trace elements; consequently, these are also added and an environment is created for desirable biological life. To our knowledge, this is one of the first instances reporting the use of trace elements for such purposes. Very rigid control is maintained over the pond environment by unique instrumentation developed by the company. A rapid photoelectric method determines the "algae count" which, correlated with the results of various chemical and biological tests indicates the amount and variety of nutrients required to maintain satisfactory biological conditions. It is interesting to note that the performance of the ponds is best in the summer when the receiving stream has the least assimilative capacity and not as efficient as in the winter when the stream flow is greater and the dissolved oxygen in the stream is not critical. The ponds treat approximately 2 million gallons of wastes per day without any reported nuisance and resulting in BOD's as low as 20 ppm with a small amount of dissolved oxygen present in the effluent. Although not directly related to this subject, it may be of some interest that one plant in Texas is disposing of around 500 gpm of process water entirely by solar evaporation and have obtained evaporation rates of from 3 to 7 gpm per acre of pond area during the past 8 or 10 years.

Admittedly, all has not been serene on the oxidation pond front. There have been failures and there have been intermittent weaknesses. These occurrences, however, represent a very small percentage of the total installations. Nonetheless, these should not be minimized at a discussion of this nature.

One disappointment has been the attempt to treat indigo dye wastes from a textile mill by ponds. Here primary treatment is provided for domestic sewage from a town of about 15,000 population. This effluent is mixed with the mill waste and discharged into a pond system comprised of two ponds operating in series totaling about 57.5 acres surface area. The industrial waste flow is about 250,000 gpd whereas the domestic flow averages about 1.5 MGD. Odor has been a constant source of complaints, but control has been attained with the addition of anhydrous ammonia in dosages up to 10 ppm.

The general objections to the green color of pond effluent is reflected in the abandonment of a pond system serving one city with the construction of a conventional complete treatment plant. The effluent was discharged into a stream which meandered through a city park. Whereas the color problem has been corrected to the satisfaction of everyone concerned, there now exists complaints of froth or foam below a small low water dam within the City. In some isolated and widely separated installations reports of scum forming and collecting in certain portions of ponds which under certain conditions gives off an odor which we have classified as a "pig pen odor". Needless to say, this is indeed a most repulsive odor. Other conditions reported involve ponds turning from green to pink and in some instances almost red. The odor nuisance here seems erratic, sometimes there is no odor and at other times there is an odor but definitely not the pig pen odor. Perhaps the most troublesome aspect of pond installations confronting the Health Department is the problem of mosquito control. Encephalitis is considered endemic in many areas of Texas, and it is known that several vectors are attracted to the type of water in oxidation ponds. However, it is also recognized that the known endemic areas are also areas of widespread irrigation practice - some using ground water and some using surface water; consequently, the mosquito problem is there without the introduction of oxidation ponds. Nonetheless, it is this potential hazard that influences us to accept ponds on a temporary or emergency basis. Studies have shown that mosquito breeding is absent or negligible in well engineered and well maintained ponds. The engineering can be controlled, but it is an obligation of the municipality to prove that they accept the responsibility for providing proper maintenance of the ponds before such installations can be accepted on an unqualified basis.

It has been interesting to observe how the use of ponds has spread to other States and numerous foreign countries during recent years, and it is gratifying to feel that perhaps in some small way our State has contributed to certain phases of this trend. In any event, it definitely appears that these ponds are with us to stay as there is far too much in their favor to cause belief that they are merely a passing fancy. Therefore, we should be moved toward the acquisition of more knowledge about the performance of these ponds so their application will be on as sound an engineering basis as possible. At the present time and with our present knowledge, can the quality of oxidation pond effluent be as confidently predetermined in the design stage as can the effluent quality from trickling filter or activated sludge plants? If not, then perhaps a second look is in order.

With regard to the use of oxidation ponds in the Southwest, we have just received the reports of a survey being made of the policies, official and unofficial thinking of the States in the Region VII area, which includes Arkansas, Oklahoma, New Mexico, Louisiana, and Texas. The purpose of this questionnaire was to obtain as much information as possible about the status of oxidation ponds in this area, to tabulate this information and to present a summary to a Regional Conference which will be held in Dallas in September with representatives of these five States. In developing the questionnaire, we attempted to include as many questions as possible so that a good cross-section picture could be obtained as to how close together the various States might be in certain areas of thinking as well as determining those areas where the States were pretty widely separated. For this reason, the questionnaire was divided into eight general divisions, with the first one attempting to determine the preference for nomenclature of ponds, the second to determine the States attitude towards ponds as to approval of ponds as a recognized method of sewage treatment. The third area covers information on basic design criteria used by the various States, and the fourth is the section to determine the type of requirements as to the location of ponds. The fifth is to determine if any experiments had been conducted on stocking ponds with fish, and the sixth is a determination of the attitude concerning utilization of pond effluent for irrigation. The seventh pertains to the disinfection of pond effluent and the last section to general comments.

After the questionnaire was developed, Mr. Carl Thompson of the Region VII Office personally took the questionnaire to the various States and filled it out to the best of his ability. In this endeavor, Mr. Thompson reported that a number of the States do not have written criteria or design standards on pond installations. Consequently, the comments included on the questionnaire indicate more or less individual thinking rather than set established regulations or requirements of the States. It should be mentioned here, also, that in some instances Mr. Thompson was not able to contact the individual in charge of this phase of work within the Health Department and, consequently, some of the recorded answers might not necessarily reflect the thinking of that particular individual. It was interesting, also, to learn that even within individual State Departments, that thinking in certain areas of oxidation pond operation differed between individuals of the Department. This is true of our State and it indicates the need for something like this questionnaire to crystallize our overall opinion so that we will not be so diversified even among ourselves.

In summarizing the results of this first go-around on the questionnaire, it is interesting to note that three of the States preferred the term "oxidation ponds" with two favoring "stabilization ponds". One State expressed a preference for the term "lagoon" where raw sewage was used.

With regard to the attitude of these States concerning ponds, three of them would accept ponds on an unqualified basis, four accepted them as a permanent type of plant, and all five accepted them on an emergency or temporary basis. Three States accept ponds for the treatment of raw sewage where an effluent is produced, whereas two will not. Four States accept them as secondary treatment units with the production of an effluent. All five States were apparently satisfied with the ponds as they are presently used. These five States reported a total of 274 ponds in operation and these ponds represent from 9 to 27 percent of the sewage treatment plants in individual States.

With regard to operational results, it is interesting to note that four of the five States report that they had received odor complaints, mosquito breeding had been observed, and excessive weed growth was existing in ponds. It is reported that only one State had received complaints about the color of the pond effluent as being objectionable. Four States reported they had made studies on operating efficiency as well as bacterial removal in ponds. All five states reported operational results generally favorable. The time pond operation had been under observation in these States varied from 3 years to 25 years.

With regard to design criteria, practically all of the States seem to base the loading on pounds of BOD per acre of surface areas and the loading figure is surprisingly close, varying from a low of 30 pounds per acre to a high of 50 pounds per acre of surface area. The five States seemed to be somewhat apart in their requirements of satisfying the organic load in that two require the total load to be satisfied in the first pond and three do not have this requirement. Four of the States, however, have a limitation on the size of the first pond. With regard to recirculation, none of the States require recirculation facilities, but two States encouraged the practice.

With reference to inlet and outlet structure, all five States appear to concur that the inlet structure should be submerged with the location varying from the center to the side. Other requirements in this area indicate the States to be somewhat separated in their feelings as indicated on the summary sheet. All States seemed to be fairly close together in their requirements of maximum, minimum, and average depth as well as free-board. The States were also in accord as to desired inside and outside slopes of dikes.

Four States have no requirements as to location of the ponds with reference to prevailing winds, although there are requirements by most of the States concerning the proximity to habitation. Location with regard to proximity to surface and ground water supplies is rather diversified.

Evidently one State encourages the stocking of these ponds with fish but the practice does not seem to have obtained much headway at this time.

All five States were together in their attitude regarding the utilization of pond effluent on restricted crops. The reports from the States on their attitude about the chlorination of pond effluent shows considerable variation, from not requiring any chlorination to the conventional attitude of requiring it where it is deemed to protect health and abate nuisance.

The general comments received from the States on this subject are rather interesting in that it is indicated that there is still some reservations in the minds of those questioned as to the application or limitation of ponds in the field of sewage treatment; however, these limitations are not specifically spelled out. The results of this survey are submitted here on an unofficial and informal basis and certainly do not reflect the official policies of these States with regard to this Subject. The purpose of submitting this summary to this symposium is to acquaint the group with an approach which has been taken in this field and an attempt to evaluate on an areawide basis the attitude of the various agencies concerning ponds with the desire to possibly unify some of the design criteria where ever possible. This survey report will be resubmitted to the individual States involved for possible revision of their replies and then it will be discussed in considerable detail at the regional technical meeting in September. This is reviewed here merely as a topic of possible interest in the event some other areas desire to conduct a similar study.

As one who was subjected to the Ehlers modus operandi for almost a quarter century, it would be a gross dereliction of duty if the potentialities of this symposium were not capitalized upon to the fullest. We, from Texas, welcome this opportunity to suggest to this symposium three principal objectives, which in our humble opinion, if attained only in part, would do much toward contributing to a successful meeting.

The first objective, we hope, would be for the proceedings of this symposium to record on one place a listing of reports of research, studies, and observations on oxidation pond performance. Undoubtedly each State or Agency represented at this symposium had conducted certain investigations of varying magnitude on some phase of pond operation. Likewise, it is safe to presume that little, if any, distribution has been given to these reports outside the rather limited confines of the individual State circles. If this meeting serves no other purpose than to gather together sources of such reports and list them in the proceedings, it will be well worth-while.

The second objective, we trust, would be initiating of discussions toward the unification of pond design criteria. Here, for possibly the first time, we have an assembly of engineers and technicians from many of the State utilizing ponds. The high calibre of technical know-how and the total number of years of experience with pond installations represented here is most impressive. Why not, then, take advantage of this opportunity to explore how close to agreement those in attendance might reach with regard to such as:

1. What should be the recommended and accepted nomenclature for engineered ponds? Waste stabilization ponds, oxidation ponds, lagoons?

2. What about raw sewage ponds? Should they be accepted without reservation on a nation-wide basis? What is the concensus of opinion about ponds for secondary treatment?

3. Is there any common limiting criteria as to location, application, or operation of ponds?

4. What about agreement on basic loading criteria? Can the unit of loading be unified, i.e. BOD per acre, ft., population per acre, detention time?

5. What is the general opinion about one pond to satisfy the loading, as against a series of ponds totaling the recommended loading?

6. Is there any common area of thinking about recirculation?

7. Is there any unified accepted policy or practice towards restrictions on pond effluent being discharged close to raw water intakes?

These are merely starting points which might prove akin to a new type of chain reaction. Suffice it is to say, however, it seems entirely appropriate and timely that such a movement toward unification be initiated by this group.

The third objective we would like to see achieved concerns research, pure and applied. Undoubtedly many, and perhaps most, of the answers to present problems lay in this area; hence a listing of these problems should be indicative of research fields. In a number of instances perhaps plant scale studies with certain controls would be adequate. As far as our experience with ponds in Texas is concerned, we feel the need for more knowledge along the following lines:

1. How can a clear effluent be produced? As previously mentioned, the algae green color of pond effluent continues to be the major objection to some users. The search for the answer to this question poses a whole gamut of propositions varying from plant design to the introduction of other forms of life.

2. We need the establishment of simple control tests on ponds to indicate pond conditions, especially when trouble might be imminent.

3. We need a test to determine the amount of nutrient which should be added to assure proper biological life. About all that is available now is the old rule of thumb that one pound of nitrogen will satisfy five pounds of BOD.

4. We need more studies to determine the correlation between pond performance and temperature (air and water) sunshine with the possibility of using this data in forecasting pond disturbances.

5. Studies are indicated concerning carbon-nitrogen-phosphorous ratios as related to pond action.

6. Investigations are urgently needed to determine the sanitary quality of pond effluents. Bacterial removal, survival of virus, etc.

7. What is the limiting factor which should control the discharge of algae laden effluent into a water course?

These are at best, only a few of the many challenges by this field of sewage treatment.

We from Texas are indeed grateful for the opportunity to present these thoughts to this symposium. It is our sincere hope this will be the beginning of a coordinated effort to advance our technical and practical knowledge of pond performance and operation so as to assure utilization for the benefit of all.

STUDIES OF RAW SEWAGE LAGOONS AT FAYETTE, MISSOURI, 1958-59 WITH A RESUME OF 1957-58 OPERATIONS

By H. C. Clare, Joe K. Neel,
and C. A. Monday, Jr.*

This lagoon investigation project was developed in 1956 when the Public Health Service, the Missouri Division of Health, and the City of Fayette, undertook an investigation of stabilization ponds to be fed Fayette sewage. The Public Health Service and the Division of Health subsidized cost of the experimental ponds; and the Service directed and conducted studies. Controlled operation began in May 1957.

DESCRIPTION

Fayette is situated in Central Missouri about midway between Kansas City and St. Louis (lat. 39° 08', long. 92° 40'). Elevation is 640' above msl. The 1950 population was 3, 144 including approximately 400 resident students of Central College. The sewered population has been estimated at 2, 700 and some seasonal variation coincides with college schedules. Municipal wastes include the normal small industries, laundries, slaughter houses and locker plants, etc. Floor washings from a "pig parlor" or automatic hog feeding pen were discharged to the municipal system in 1957 and 1958.

TREATMENT FACILITIES

The lagoon or "pond" installation is shown in Figure 1. Sanitary sewer lines shown by manholes end at a wet well from whence sewage is pumped up to the distributor shown in Figure 2. A bypass line extends from a manhole to the creek as indicated. The piping system allows selective division of the sewage load among the various units, series operation, etc. Sewage is apportioned to various units as desired by dividing flow off the conical distributor apron with movable partitions. It was necessary to install an annular orifice around the upper part of the cone to secure uniform distribution down the apron. Excess sewage passes through waste holes to the 15-acre lagoon.

The five small ponds are each one acre in area when filled to a depth of five feet, and three-fourths acre each when liquid is two and one-half feet deep. Two and one-half feet is the minimum possible overflow level, and the maximum operational depth is about six feet. The large pond is fifteen acres in area at its usual operating depth of about three feet. It receives effluent from the small ponds, and any raw sewage not used in their controlled loadings.

A report covering the first 13 months' operation (1) has been prepared and submitted for publication; however, for purposes of this symposium, it appears appropriate to briefly review findings reported therein before entering into details of subsequent investigations.

SUMMARY 1957-58 OPERATIONS

Operation during the first phase involved sewage division, retention, etc. shown in Table 1. Average sewage flow was 0.216 mgd and average B. O. D. load was 457 pounds per day.

LAGOON CONDITIONS

Sewage was turned into the lagoons in November 1956. Algae quickly developed in Cell 6, and in about one month in other units which at first received intermittent discharge. *Chlamydomonas* and *Euglena*

---

*Respectively, Regional Program Director and Regional Biologist, Water Supply and Pollution Control, Department of Health, Education, and Welfare, Public Health Service, Region VI, Kansas City, Missouri, and Resident Biologist, Experimental Lagoon Project, Fayette, Missouri.

Preceding page blank

TABLE 1

AVERAGE DAILY RAW SEWAGE LOAD TO LAGOONS

Cell	Acre Acres	Depth Feet	Volume (GPD)		Theoretical Detention Days	B.O.D. (Pounds)			
						Planned		Realized	
			Per Cell	Per Acre		Per Cell	Per Acre	Per Cell	Per Acre
1	0.75	2.5	7000	9000	87	15	20	15.2	20.3
2	0.75	2.5	14000	18000	44	30	40	30.4	40.5
3	0.75	2.5	21000	28000	29	45	60	45.6	60.8
4	0.75	2.5	28000	37000	22	60	80	60.8	81.1
5	0.75	2.5	35000	47000	17	75	100	76.6	101.3
6	15.00	3.0	111000	7000	68	255	16	229.0	15.3

were the first phytoplankters to appear. Blue-green algal mats developed in ponds with loadings less than 60 pounds B.O.D./acre/day in summer of 1957. They developed from detached patches of benthic algae (*Phormidium*). Denser plankton growths in cells with heavier loadings apparently kept light at the bottom below the intensity required for prolific benthic growth. Ice cover was intermittent during the winter of 1957-58, but endured once for 31 days. Blue-green algal mats gave off pig pen odors, and cells loaded in excess of 60 pounds B.O.D./acre/day permeated the immediate surroundings with sulfides for several days after disappearance of ice cover in February 1958.

PERFORMANCE

Average values and percent removals of major sewage components at varied loadings appear in Table 2. Table 3 shows extent of coliform-type bacteria survival.

Performance of the entire facility was outstanding and quality of the final effluent was maintained at a high level. Purification achieved by individual small units was very good on a monthly basis, but cells with daily B.O.D. loadings of 60-100 pounds/acre had an oxygen demand that could not be satisfied by rate of photosynthesis possible under ice cover.

BIOLOGICAL FEATURES

The following photosynthetic organisms were observed in the plankton of the six ponds:

Green Algae

Volvocales

- *Chlamydomonas* spp. (3)
- *Chlorogonium elongatum* Dangeard
- *Pascheriella tetras* Korshikov
- *Pandorina morum* Bory
- *Carteria* sp.

Chlorococcales

- *Chlorella vulgaris* Beyerinck
- *Golenkinia radiate* Chodate
- *Micractinium pusillum* Fresenius
- *Ankistrodesmus falcatus* (Corda) Ralfs
- *Scenedesmus dimorphus* (Türp.) Kütz. - most common *Scenedesmus*
- *Scenedesmus* sp.
- *Actinastrum hantzschii* lagerheim
- *Coelastrum cambricum* Arch.
- *Oocystis* sp.
- *Tetraedron* sp.

Euglenophyta

- *Euglena proxima* Dangeard
- *Euglena proxima* var. *amphoraeformis* Szabados
- *Euglena acutissima* Lemmerman
- *Phacus* sp.

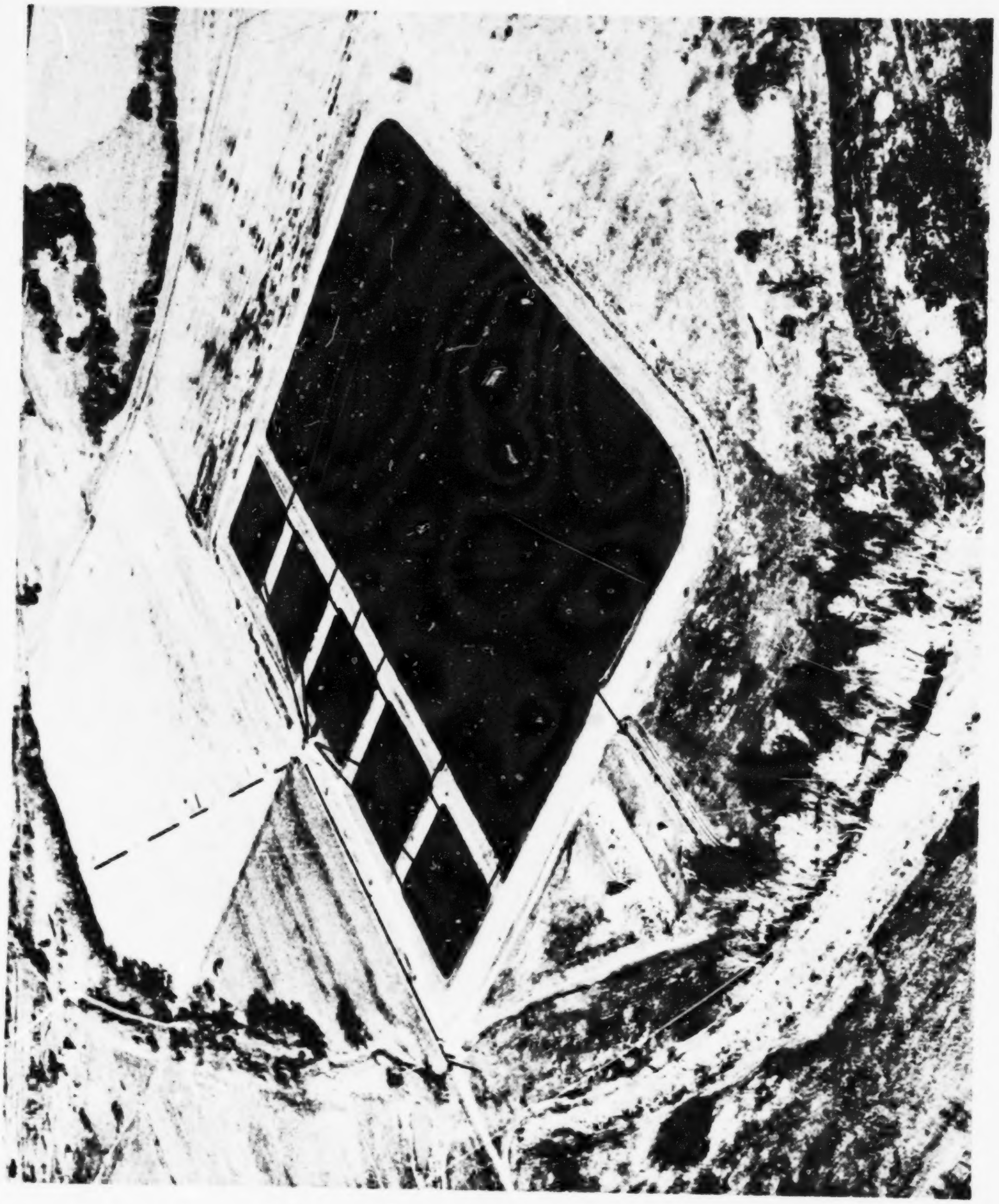


FIGURE 1 - Aerial View of Fayette Lagoon Facility

TABLE 2

Average Concentrations and Percent Removal of Waste Components

Monthly Averages

	Total Alk.	O_2	BOD ppm	Org. P ppm	PO_4 ppm	Total P	Org. N ppm	NH_3-N ppm	Total N	Coliform MPN
Raw Sewage	255	--	267	12.2	30.5	42.7	129.2	31.4	160.6	40,752,460
Cell 1 (20 lbs. BOD/acre/day)	174	16	34	2.2	6.0	8.2	5.6	5.8	11.4	13,010
2 (40 lbs. BOD/acre/day)	178	15	38	2.5	7.2	9.7	6.7	7.1	13.8	20,158
3 (60 lbs. BOD/acre/day)	187	14	48	3.6	10.2	13.8	10.0	8.4	18.4	27,595
4 (80 lbs. BOD/acre/day)	199	11	49	3.4	9.4	12.8	8.7	8.7	17.4	34,013
5 (100 lbs. BOD/acre/day)	191	11	47	3.4	9.4	12.8	8.5	8.6	17.1	64,490
6	175	13	30	2.4	6.3	8.7	6.0	5.6	11.6	14,802

Percent Removal*

Cell 1	Average	33	--	87	81	80	80	96	81	93	99.9996
	Maximum	42	--	90	96	90	92	98	89	97	99.9999
	Minimum	26	--	84	55	61	62	93	63	88	99.9991
Cell 2	Average	31	--	86	77	75	76	95	77	92	99.9995
	Maximum	39	--	89	97	87	90	98	88	96	99.9999
	Minimum	17	--	82	52	56	60	92	51	85	99.9989
Cell 3	Average	28	--	82	69	66	67	92	73	89	99.9992
	Maximum	44	--	87	87	81	83	95	93	94	99.9999
	Minimum	19	--	72	55	35	41	89	63	82	99.9970
Cell 4	Average	26	--	81	67	67	67	92	71	89	99.9991
	Maximum	48	--	89	97	85	88	97	89	96	99.9998
	Minimum	7	--	72	27	31	33	75	53	81	99.9976
Cell 5	Average	26	--	82	67	67	67	93	72	89	99.9984
	Maximum	42	--	87	88	83	84	97	87	96	99.9999
	Minimum	15	--	72	34	38	43	87	51	80	99.9902
Cell 6	Average	32	--	89	78	78	80	95	82	93	99.9996
	Maximum	43	--	96	92	91	98	98	93	97	99.9999
	Minimum	21	--	86	66	68	68	90	56	84	99.9982

*Do not necessarily check with average values above as some analyses were not performed every month in lagoons.

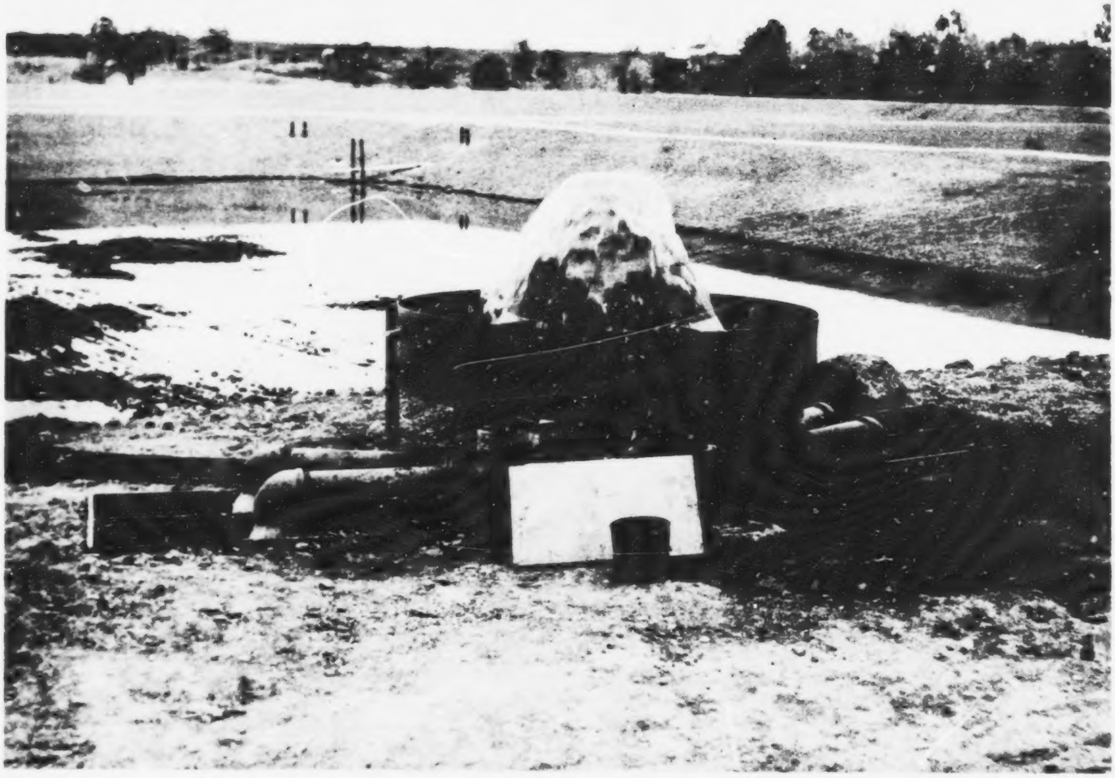


FIGURE 2 - Sewage Distributor

TABLE 3

SURVIVAL OF COLIFORM-TYPE BACTERIA

Loading	Effluent Range			Percent of Samples Equal to or Greater than	
Pounds B.O.D./A-day	Min. Value	Arith Ave.	Max. Value	43,000/100 ml	93,000/100 ml
20	430	14,700	43,000	16	0
40	3,600	24,700	93,000	29.5	7.9
60	430	24,300	93,000	24.5	8.9
80	2,400	34,000	93,000	48	18
100	2,400	40,000	93,000	47	19.2

Diatoms

Nitzschia sp.

Blue-Green Algae

Oscillatoria sp.
Anabaena flos-aquea (Lyngb.)
Brebisson

Euglena proxima and its variety amphoraeformis showed a high degree of adaptability to lagoon conditions. They were present at all seasons and were not precluded by any rate of loading or climatological condition. Next in line of tolerance were Chlamydomonas, Micractinium, Ankistrodesmus, Scenedesmus, Chlorella, and Chlorogonium. Euglena and Chlamydomonas tended to dominate during cooler weather and the various Chlorococcales were usually the most numerous organisms in summer months.

Phytoplankton density varied from monthly averages of 347 to 34,773 ppm by volume and from 24,877 to 2,860,000 organisms per ml. Greatest production was in cells with raw sewage loadings of 60 pounds B.O.D./acre/day and above. Growth seemingly increased with load up to 60 pounds B.O.D./acre/day and then leveled off. Samples were from effluents which were discharged from very near the surface. Uppermost water layers are often avoided by phytoplankters during seasons of high light intensity, and maximum densities during summer months were probably not represented by effluents. Volume and number of phytoplankters often exhibited varying trends as relatively small numbers of larger organisms often produced the greatest mass. When qualitatively similar populations endured for any period of time, volume and number had similar fluctuations. Lowest densities were recorded as units lost oxygen under ice cover, and greatest development was in spring. Observed maximum showed no relationship to loading, but no assurance exists that all or any actual maxima were represented in samples, certainly not during summer months.

Life processes of algae had a powerful influence on pond chemistry and biology. Photosynthesis was necessary for occurrence of detectable oxygen, as absorption from the air could not alone satisfy immediate oxygen demands. This process also utilized free and half bound CO_2 and reduced alkalinity and mineral content; it elevated pH to very alkaline ranges during daylight hours, provided for utilization of nitrogen in the ammonia stage, and so eliminated oxygen demand inherent in nitrification to nitrite and nitrate, and was primarily involved in reduction of other plant nutrients. Alternation of dominance between photosynthesis during the day and aerobic decomposition-respiration at night provided conservation of energy and kept each process near peak activity. Photosynthesis is supported primarily by CO_2, the waste product of aerobic decomposition and respiration, and the latter processes rely upon oxygen, the waste product of photosynthesis.

LOADING CONSIDERATIONS

Solar radiation was measured at the lagoon site and its variation related to oxygen production and other factors. It had much control over photosynthetic rate, but this process was also stimulated or depressed by fluctuations in nutrient supply. Cell 6 developed maximum photosynthetic intensity during seasons with lowest solar radiation when nutrients increased in effluents from some other cells after declines in their rate of photosynthesis. This unit functioned largely as a second cell of an in-series operation and restored effluent quality after it had deteriorated in cells with heaviest raw sewage loads. Applications of 60 pounds B. O. D. /acre/day or more seemingly maintained a nutrient supply that would consistently support photosynthesis up to the limitations imposed by available light. However, loads of this magnitude produced an oxygen demand that could not be satisfied by reduced rate of photosynthesis under ice cover and they then lost all oxygen. Heavier loadings were considerably more efficient in open water seasons as percent removal of waste components was about the same at all loadings. Lighter loadings did not impose an oxygen demand that was beyond the capacity of photosynthesis under ice cover and free oxygen was maintained.

The above details suggested that purification processes would proceed to the best effect with high summer and low winter loadings. A 2-cell in-series facility appeared to be the most economical and least troublesome approach to this end.

The importance of photosynthesis in maintenance of oxygen and influences of light thereupon led to a search for a method of basing loading rate (pounds B. O. D. /acre/day) upon the annual solar radiation minimum (average langleys/day/month). Solar radiation can be no reliable guide if ice cover exists for any appreciable time, but in regions without ice cover it appears that about 1.5 langleys per day are required to maintain oxygen with a load of one pound of B. O. D. /acre/day. To allow a safety factor, it appeared that preliminary loading rate for an ice-free area may be determined by dividing the minimum monthly solar radiation value (average langleys per day) by 2. A table listing minimum annual values at all accredited North American and some insular radiation stations was developed for use in this respect.

1958-1959 OPERATIONS

In June 1958, all sewage was temporarily turned into the 15-acre unit and operations changed as follows: Load was increased to 120 pounds B. O. D. /acre/day in Cell 1 and to 100 pounds/acre/day in Cell 3, and decreased to 60 pounds/acre/day in Cells 4 and 5; water depth was raised to 5 feet in Cell 4; and Cell 2 was placed in series operation, receiving only effluent from Cell 3. These modifications went into effect July 1, 1958, and continued through April 1959. Raw sewage load to Cell 6 was about 8 pounds B. O. D. / acre/day during this period.

Average monthly climatological conditions appear in Table 4. The pyrheliometer was out of service from early July until December, and solar radiation is not included. Lagoons became ice-covered on November 28, were open for three days beginning December 28, and then covered again until February 23 (Cells 1, 3, and 5) and February 24) Cells 2, 4, and 6). Snow cover was intermittent.

Average sewage volume was as follows:

July 1958	109,046 gpd
August	218,911
September	199,697
October	217,837
November	198,716
December	193,563
January 1959	198,717
February	203,785
March	300,808
April	317,679

The 10-month mean was 215,876 gpd, or essentially the same as the 0.216 mgd reported for the 13-month period ending May 30, 1958.

Sewage and pond records will be considered together whenever possible in order to expedite consideration of performance realized from varied loading rates and series operation. This section considers only surface lagoon samples.

TABLE 4

CLIMATOLOGICAL DATA

	Temperature °F			Precip. Inches	Evaporation Inches*	Air Movement Miles/Mo.
	Average	Av. Max.	Av. Min.			
1958						
July	74.4	83.2	65.5	12.88	6.5	1749
August	75.4	86.5	64.2	.73	5.1	1615
September	67.7	79.6	55.8	2.26	4.6	2300
October	57.2	71.0	43.3	1.16	3.25	2467
November	47.3	59.9	34.7	2.93	2.4	3173
December	29.1	39.7	18.4	.55	---	3145
1959						
January	23.1	33.3	12.9	1.37	---	4098
February	31.7	41.2	22.2	2.03	---	3536
March	43.4	55.3	31.5	3.39	---	4538
April	53.5	65.2	41.8	3.23	4.3	3712
TOTAL	---	---	---	30.53	26.15	30333

*From Ponds.

CHEMICAL FEATURES

Biochemical Oxygen Demand

TABLE 5

AVERAGE B.O.D.'s (PPM) AND PERCENT REMOVAL IN EACH CELL

	Raw	Cell					
		1	2	3	4	5	6
1958							
July	253	23	27	42	22	35	--
August	255	39	21	38	26	37	27
September	285	51	18	39	38	44	25
October	285	61	21	43	33	36	33
November	289	51	22	46	37	35	30
December	286	58	25	51	43	38	34
1959							
January	267	69	25	55	48	51	24
February	272	77	40	67	52	54	29
March	243	55	36	66	51	56	34
April	247	47	30	49	52	52	33
10 Mo. Ave.	268	53	26	50	40	44	30
% Reduction	---	80	90	81	85	84	89

Series operation resulted in greatest purification in this respect, and Cells 2 and 6 (purely secondary and nearly complete secondary cells, respectively) showed almost identical performance, although Cell 6 never quite reached the low or high monthly extremes noted in Cell 2 (Table 5). Of cells receiving only raw sewage, performance was best in Cells 4 and 5, where loading was kept at 60 pounds B.O.D./acre/day.

Phosphorus

The story here (Table 6) is essentially as told for B. O. D.: Most reduction was achieved through series or largely series operation, and lighter raw sewage loadings (60 pounds B. O. D. /acre/day) allowed greater phosphorus consumption than those in excess of 100 pounds B. O. D. / acre/day.

Nitrogen

Here again (Table 7) series operation resulted in greater consumption but individual differences were not as striking as those noted for B. O. D. and phosphorous. Secondary and partly secondary cells showed to the greatest advantage in removal of ammonia, but they also exceeded other cells to a slight degree in removal of organic N and to a marked extent in use of nitrate. Seemingly, no nitrate was produced by bacterial actions in the ponds and amounts contributed in raw sewage were largely or completely utilized at times in all cells. No nitrite occurred.

Specific Conductance

This test measures total electrolyte and to a large degree serves as an index of gross mineral content. Percent removals do not appear appropriate here since raw sewage records are missing for four months, but average concentrations show again the advantages of series operation.

Alkalinity

Greater removal was accomplished by series or partial series operation (Table 9) but varied loading to the raw sewage cells had insignificant effects upon alkalinity loss. Carbonate alkalinity occurred only during those months with appreciable photosynthesis and disappeared in units with raw sewage loadings in early December upon the appearance of ice cover November 28. In Cell 2, it was absent in February only, but it was always found in Cell 6. Carbonate returned to all units when photosynthesis increased in April.

Oxygen

Oxygen disappeared from Cell 1 October 3, returned on October 16, and remained until December 16, and was then absent until April 6. Lagoons 3, 4, and 5 maintained oxygen for 15-20 days after surfaces became frozen November 28, and were thereafter oxygenless until early and late April. Cell 2 lacked oxygen over the period February 7 to March 1, but anaerobic conditions were never discovered in Cell 6. Monthly and over-all averages (Table 10) illustrate major characteristics of various units and show better average conditions in secondary units, although maximum production therein seldom reached levels displayed by units receiving raw sewage.

BIOLOGICAL FEATURES

Coliform-Type Bacteria

Average densities (MPN) and percent reductions in these bacteria are shown in Table 11. Greatest purification occurred in the secondary cells (2 and 6) and poorest performance in this respect was with raw loadings in excess of 100 pounds B. O. D. /acre/day.

Phytoplankton

Average monthly concentrations appear in Table 12. Sampling frequency varied from 3 to 5 times per month and there can be no assurance that monthly maximums or minimums were included. With one exception, greatest growth was in spring and summer. All minimums were reached in late winter under ice cover. Relationships to oxygen production may be noted by reference to Table 10. No definite relationship existed between average oxygen concentration and plankton mass in any cell. Free oxygen may increase with greater production or lesser consumption. During cold weather consumption decline appeared more responsible for oxygen levels noted in Cell 6 as algal concentration was then in its lower ranges.

Cell 4 realized only about 60 percent of the plankton production found in Cell 5. This difference indicated another limitation imposed by confinement of waste materials to deeper levels by stratification. Slightly higher B. O. D. values in Cell 5 probably resulted from greater plankton densities in its surface water.

TABLE 6

Average Phosphorus Concentrations (ppm) and % Reductions Attained in Individual Cells

	Organic P							PO$_4$							Total P						
SOURCE	R	1	2	3	4	5	6	R	1	2	3	4	5	6	R	1	2	3	4	5	6
1958																					
July	14	0.7	0.3	0.7	0.4	0.6	---	32	1.8	0.6	1.8	1.0	1.3	---	46	2.5	0.9	2.5	1.4	1.9	---
August	15	2.4	1.2	1.8	1.2	1.8	1.2	35	5.8	2.7	4.3	3.1	4.4	3.0	50	8.2	3.9	6.1	4.3	6.2	4.2
September	11	2.5	0.5	1.7	1.7	1.9	1.1	27	6.3	1.3	4.5	4.3	4.7	2.8	38	8.8	1.8	6.2	6.0	6.6	3.9
October	14	3.1	0.7	2.1	1.9	1.7	1.3	33	7.5	1.8	5.1	4.6	4.3	3.1	47	10.6	2.5	7.2	6.5	6.0	4.4
November	15	2.1	0.8	1.9	1.9	1.4	1.3	36	5.1	1.9	4.6	4.7	3.8	3.3	51	7.2	2.7	6.5	6.6	5.2	4.6
December	12	2.9	0.7	2.5	1.7	1.8	1.3	30	7.5	1.7	6.2	4.2	4.5	3.3	42	10.4	2.4	8.7	5.9	6.3	4.6
1959																					
January	13	3.4	1.0	2.7	2.4	2.9	1.1	33	8.3	2.2	6.9	6.1	7.2	2.9	46	11.7	3.2	9.6	8.5	10.1	4.0
February	10	6.2	2.2	4.2	3.3	2.6	1.5	27	15.7	5.7	10.8	8.4	6.5	3.9	37	21.9	7.9	15.0	11.7	9.1	5.4
March	11	3.4	1.1	2.9	2.7	2.0	1.5	28	8.6	2.8	7.4	6.8	5.0	3.7	39	12.0	3.9	10.3	9.5	7.0	5.2
April	13	4.2	0.9	2.4	2.4	2.0	1.4	31	10.4	2.3	5.8	5.9	5.2	3.7	44	14.6	3.2	8.2	8.3	7.2	5.1
10 Mo. Av.	13	3.1	0.9	2.3	2.0	1.8	1.3	31	7.7	2.3	5.7	4.9	4.7	3.3	44	10.8	3.2	8.0	6.9	6.6	4.6
% Red.		76	93	82	85	86	90		75	93	82	84	85	89		75	93	82	84	85	90

TABLE 7

Average Concentrations (ppm) and % Removals of Nitrogen Compounds

	Organic N							NH$_3$-N							Total N (Organic N ≠ NH$_3$-N)							NO$_3$-N						
	R	1	2	3	4	5	6	R	1	2	3	4	5	6	R	1	2	3	4	5	6	R	1	2	3	4	5	6
1958																												
July	131	3.2	3.7	2.7	2.5	4.7	---	32	3.2	3.5	2.8	2.5	4.5	---	163	6.4	7.2	5.5	5.0	9.2	---	0.25	0	0.005	0	0	0.1	-
August	124	4.5	1.5	4.8	3.2	4.6	3.1	29	4.5	1.4	4.8	3.3	4.6	3.1	153	9.0	2.9	9.6	6.5	9.2	6.2	0.4	0	0	0.02	0	0	0
September	112	3.7	1.3	4.4	6.7	4.8	2.5	28	3.7	1.2	4.5	6.6	5.1	2.6	140	7.4	2.5	8.9	13.3	9.9	5.1	0.5	0.03	0	0	0.1	0	0
October	120	6.2	1.6	5.1	4.6	3.9	3.0	29	5.8	1.6	5.0	4.6	4.0	3.0	149	12.0	3.2	10.1	9.2	7.9	6.0	0.8	0.2	0	0.1	0	0.08	0
November	---	4.3	1.9	4.2	4.1	3.5	3.5	38	4.0	1.9	4.2	4.1	3.4	3.5	---	8.3	3.8	8.4	8.2	6.9	7.0	0.4	0.2	0	0.05	0.03	0	0
December	120	5.0	1.6	5.9	4.2	5.4	2.9	29	4.3	1.6	5.7	4.1	5.2	3.0	149	9.3	3.2	11.6	8.3	10.6	5.9	0.7	0.2	0	0.1	0.05	0.1	0
1959																												
January	134	9.1	2.7	5.5	4.2	5.8	2.6	33	9.0	2.7	5.2	4.2	5.8	2.6	167	18.1	5.4	10.7	8.4	11.6	5.2	0.6	0.2	0	0.2	0	0.1	0
February	122	15.9	4.6	8.7	7.7	7.1	3.0	30	15.0	4.6	8.2	7.5	6.7	3.1	152	30.9	9.2	16.9	15.2	13.8	6.1	0.8	0.4	0	0.3	0.1	0.1	0
March	118	7.3	3.2	7.8	6.2	5.3	3.6	29	7.2	3.0	7.3	6.2	5.1	3.5	147	14.5	6.2	15.1	12.4	10.4	7.1	0.7	0.1	0.03	0.2	0	0.1	0
April	---	----	---	---	---	---	---	--	----	---	---	---	---	---	---	----	---	----	----	----	---	----	----	-----	----	----	----	-
10 Mo. Av.	122	6.6	2.4	5.4	4.8	5.0	3.5	31	6.3	2.4	5.3	4.8	4.9	3.5	152	12.9	4.8	10.8	9.6	9.9	6.7	0.6	0.15	0.004	0.2	0.03	0.06	0
% Red.		95	98	96	96	96	97		80	94	83	85	84	89		92	97	93	94	93	96							

TABLE 8

AVERAGE SPECIFIC CONDUCTANCE (MICROMHOS PER CM)

	R	1	2	3	4	5	6
July 1958	675	420	400	480	400	450	---
August	---	508	395	488	368	455	438
September	---	500	407	510	433	450	400
October	---	600	393	600	467	556	430
November	---	613	314	619	595	588	395
December	925	563	353	513	444	463	380
January 1959	1167	600	450	617	617	600	400
February	1100	870	589	833	742	767	467
March	1100	913	700	881	875	850	575
April	1083	900	567	850	908	917	517

TABLE 9

AVERAGE ALKALINITY CONCENTRATIONS (PPM) AND PERCENT REDUCTION TOTAL ALKALINITY

	CO_3						HCO_3							TOTAL						
	1	2	3	4	5	6	R	1	2	3	4	5	6	R	1	2	3	4	5	6
July 1958	37	16	0	15	22	20	277	124	159	181	180	173	144	277	161	175	181	195	195	164
Aug.	46	47	37	45	49	30	274	131	109	134	95	106	119	274	177	156	171	140	155	149
Sept.	29	20	30	22	37	17	273	147	139	140	143	121	137	273	176	159	170	165	158	154
Oct.	6	15	32	31	37	18	280	192	157	141	137	130	139	280	198	172	173	178	167	157
Nov.	22	19	8	23	30	9	288	149	146	166	144	137	146	288	171	165	174	167	167	155
Dec.	5	27	3	3	2	15	281	194	135	182	169	179	145	281	199	162	185	172	181	160
Jan. 1959	0	29	0	0	0	14	294	216	133	196	187	196	143	294	216	162	196	187	196	157
Feb.	0	0	0	0	0	12	289	211	186	209	205	203	145	289	211	186	209	205	203	157
March	0	25	0	0	0	52	266	202	167	211	219	213	98	266	202	192	211	219	213	150
April	13	29	21	4	15	42	290	195	169	184	206	192	104	290	208	188	205	210	207	146
10 Mo. Av.	16	23	13	14	19	23	281	176	150	174	168	165	132	281	192	172	187	184	184	155
% Red.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	32	39	34	35	35	45

TABLE 10

AVERAGE OXYGEN CONCENTRATIONS (PPM)

	1	2	3	4	5	6
July 1958	11.3	4.3	3.9	3.7	5.0	7.0
August	21.0	20.7	19.3	17.7	21.6	8.8
September	16.0	14.6	16.4	13.3	17.8	10.9
October	4.7	11.8	16.0	17.3	18.4	9.9
November	14.1	12.5	10.0	14.2	15.8	9.4
December	4.7	11.5	4.1	3.9	3.4	8.9
January	0	10.8	0	0	0	8.9
February	0	1.4	0	0	0	10.5
March	0	9.0	0	0	0	12.7
April	10.2	9.1	7.6	1.5	6.1	8.8
10 Mo. Av.	8.2	10.6	7.7	7.2	8.8	9.6

TABLE 11

AVERAGE COLIFORM (MPN/100 ml x 10^3) DENSITIES AND PERCENT REDUCTIONS

	Cell						
	Raw	1	2	3	4	5	6
July 1958	43,000	3.6	4.3	43.0	0.93	4.3	---
August	45,825	16.4	1.6	5.5	2.3	4.7	4.7
September	172,000	7.6	0.59	6.0	4.06	5.9	2.9
October	361,500	38.6	1.5	16.5	5.9	26.5	8.0
November	277,250	24.9	2.7	37.4	16.4	5.6	4.7
December	45,825	24.9	2.5	37.4	13.3	9.5	5.5
January 1959	317,666	59.6	4.7	30.1	18.8	30.1	5.9
February	205,333	76.3	17.2	59.6	48.4	18.9	17.2
March	17,200	30.2	17.2	59.6	46.8	17.2	4.3
April	18,866	31.7	4.3	31.7	59.7	43.0	5.9
10 Mo. Av.	150,446	31.4	5.7	32.7	21.7	16.6	6.6
% Reduction		99.98	99.99	99.98	99.99	99.99	99.99

TABLE 12

AVERAGE PHYTOPLANKTON DENSITY (PPM BY VOLUME)

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
August 1958	5,454	972	4,553	1,656	5,726	2,559
September	3,122	1,976	6,712	3,857	4,497	3,693
October	1,735	16,113	2,719	3,152	1,971	1,752
November	772	1,434	2,930	703	3,333	665
December	390	875	974	374	1,005	930
January 1959	253	527	386	169	190	702
February	172	111	120	39	12	518
March	883	2,038	1,752	613	534	2,760
April	3,603	3,134	2,053	341	4,879	3,051
August-April	1,851	3,658	2,573	1,542	2,532	1,841

PHYSICAL FEATURES

Temperature

Average monthly surface temperatures (Table 13) differed but little from cell to cell. Although it cannot be assumed that some variations did not result from differences in time of measurement, it appears that raw sewage kept ponds slightly warmer in winter than did effluent from primary units. During other season, temperature was more directly controlled by weather conditions.

Vertical series of temperature readings were made upon several dates to check upon extent of mixing within the ponds. Measurements were often taken at 6-inch intervals, and a difference of 1° C over this distance was assumed to indicate separate water layers. This procedure appeared conservative in view of the characteristic decline of 1° C per meter in thermoclines of lakes and reservoirs. Chemical features sometimes indicated that water layers were not as distinct and separate as suggested by temperature differences, but it soon became apparent that photosynthesis was at times possible for some distance down and its effects upon water chemistry were similar in various layers. Upon several occasions chemical features indicated separate water strata. Chemical and thermal aspects are related in the following section.

TABLE 13

AVERAGE SURFACE TEMPERATURES °C

	1	2	3	4	5	6
July 1958	28	27	28	28	28	27
August	31	30	30	31	31	30
September	28	28	28	27	27	26
October	20	22	21	21	21	23
November	12	12	13	12	12	12
December	2	1	2	2	2	1
January 1959	2	1	3	2	2	1
February	5	4	6	5	5	4
March	10	9	10	10	10	10
April	13	13	14	14	14	14

STRATIFICATION

Representative vertical measurements made in Cells 4 and 5 in July, August, September, October, and November 1958 appear in Table 14. These two cells received the same quantity of raw sewage (28,000 gpd), but Cell 4 was 5 feet deep and Cell 5, 2 1/2 feet deep. Development of thermal layers and effects of photosynthesis or decomposition-respiration within individual strata are illustrated.

Layers in each lagoon varied from 6 to 18 inches in thickness. Alkalinity and pH were most influenced by decomposition in deeper layers and photosynthetic effects were most pronounced near the surface. Photosynthesis, when evident, was always more intense at the 6-inch depth than at the surface. In Cell 4, oxygen production apparently did not occur below 18 inches, but it was present in deeper layers in September, October, and November. In Cell 5, photosynthesis often occurred at 30 inches. It is evident from change in alkalinity concentration at the bottom that Cell 4 experienced a period of complete circulation in early September, and that Cell 5 was first mixed sometime between August 4 and 11. Stratification could have been broken up at other times between sampling dates. Complete circulation evidently promoted better light penetration in Cell 5 and its entire liquid depth was thereafter brought under the influence of photosynthesis and aerobic activities. In Cell 4, photosynthesis did not extend as deeply and oxygen reached lower

TABLE 14

Vertical Measurements in Cells 4 and 5, 1958

Cell 4

	Depth	°C	pH	Alk.		O_2
				CO_3	HCO_3	
July 8 11:00 a.m.	0	28.5	7.6	0	220	1.7
	6"	28.5	7.7	0	224	3.2
	12"	27.0	7.4	0	226	Tr.
	18"	27.0	7.3	0	232	0
	24"	25.5	7.2	0	235	0
Aug. 4 2:00 p.m.	0	31.0	9.8	84	49	17.8
	6"	31.0	10.1	94	38	19.0
	12"	28.0	8.0	0	145	7.6
	18"	27.0	7.2	0	188	0
	54"	25.0	7.1	0	192	0
Aug. 11 9:15 a.m.	0	30.0	9.0	38	101	13.7
	6"	30.0	9.0	42	96	19.7
	18"	29.0	8.7	28	110	14.6
	36"	28.0	7.6	0	191	0
	60"	26.0	7.1	0	206	0
Aug. 19 12:30 p.m.	0	33.0	9.1	46	95	20.8
	6"	33.0	9.3	56	84	23.6
	18"	27.0	8.1	4	145	6.4
	36"	26.0	7.3	0	201	0
	60"	25.0	7.1	0	212	0
Sept. 8 9:20 a.m.	0	28.5	8.4	16	135	13.2
	18"	25.0	8.2	4	148	9.3
	60"	22.0	7.1	0	196	0
Sept. 18 2:30 p.m.	0	28.0	8.2	8	171	8.9
	6"	28.0	8.3	10	170	8.9
	12"	27.5	8.1	4	176	8.5
	18"	26.0	8.0	Tr.	178	8.1
	24"	25.0	7.9	0	183	6.9
	36"	25.0	7.7	0	183	5.4
	60"	23.0	7.6	0	189	4.6
Oct. 1 2:30 p.m.	0	24.0	9.0	42	123	19.6
	24"	21.0	8.4	14	153	11.3
	60"	20.0	7.3	0	193	1.9
Nov. 27 2:00 p.m.	0	8.0	8.4	14	156	10.8
	18"	6.0	8.1	2	170	8.7
	30"	6.0	8.0	0	178	7.1
	60"	4.0	7.2	0	196	1.2

Cell 5

	Depth	°C	pH	Alk.		O_2
				CO_3	HCO_3	
July 8 11:00 a.m.	0	28.5	7.1	0	226	0
	6"	28.5	7.1	0	234	0
	12"	27.0	7.1	0	234	0
	18"	27.0	7.0	0	237	0
	24"	25.5	6.8	0	246	0
Aug. 4 2:00 p.m.	0	35.0	9.6	78	74	27.4
	6"	32.0	9.8	96	54	35.6
	12"	30.0	9.3	52	103	17.5
	18"	27.0	7.1	0	212	0.6
	30"	27.0	7.1	0	224	0
Aug. 11 9:15 a.m.	0	31.0	9.0	42	111	19.0
	6"	31.0	9.1	42	111	20.1
	18"	31.0	9.0	40	114	19.7
	30"	28.0	8.6	24	131	12.4
Aug. 19 12:30 p.m.	0	31.0	9.2	50	105	28.9
	6"	31.0	9.3	56	99	29.6
	18"	29.0	9.0	42	115	27.2
	30"	27.5	8.7	26	132	18.7
Sept. 18 2:10 p.m.	0	27.5	9.0	40	110	18.3
	6"	27.0	9.1	42	107	19.6
	12"	27.0	8.9	36	115	17.5
	18"	26.0	8.4	16	134	10.8
	24"	25.0	8.1	Tr.	154	9.3
Sept. 23 10:10 a.m.	0	27.0	8.9	36	120	18.2
	6"	27.0	8.9	38	118	18.5
	18"	26.0	8.8	30	126	16.3
	30"	25.0	8.1	4	153	11.1

layers only through mixing of water strata. Periods of complete circulation did not coincide with any series of depth measurements but they undoubtedly occurred.

It seems reasonable to assume that complete mixing of a stratified pond will lower oxygen concentration in surface waters after anaerobic products are brought up from near the bottom. No observations were made during a time of full circulation in 1958, but some 1959 records clearly demonstrated loss of oxygen following complete circulation in Cell 4 in August and September (Table 15). Cell 5 maintained more complete circulation in August 1959 and did not lose oxygen until the advent of ice cover. More detailed reports on 1959 studies will appear later.

Examination of Tables 14 and 15 should indicate upward travel of waste products in stratified ponds with progressive purification. Upper layers mask the oxygenless condition of the depths, and stratification imposes an anaerobic-aerobic series operation. However, reference to Tables 5, 6, 7, 8, and 11 will indicate no increase in efficiency through this type of operation, and it involves a constant hazard of odor production with each period of complete circulation. Greater accumulation of anaerobic products delayed oxygen recovery after ice melt.

TABLE 15

DEVELOPMENT OF COMPLETE CIRCULATION AND RETURN OF STRATIFICATION IN CELL 4, 1959 (TEMPERATURE AND O_2)

Depth	8/26		8/27		8/28		8/29		8/30		8/31		9/3	
	°C	O_2	°C	O_2	°C	O_2	°C	O_2	°C	O_2	°C	O_2	°C	O_2
0"	31.0	13.6	27.5	0.2	28.0	3.9	29.5	0	28.0	0	27.5	0	30.5	9.4
6"	31.0	--	27.5	0.5	28.0	2.9	28.5	0	27.5	0	27.5	0	30.0	7.2
12"	29.5	--	27.5	0.5	27.5	0.3	27.0	0	27.0	0	27.0	0	29.0	0.4
18"	28.5	--	27.5	0	27.5	0	26.5	0	25.5	0	26.5	0	27.5	0
24"	27.5	0	27.5	0	25.5	0	25.5	0	25.5	0	26.5	0	25.5	0
30"	27.0	0	27.0	0	27.0	0	25.5	0	25.5	0	26.0	0	25.5	0
36"	26.5	0	26.5	0	27.0	0	25.5	0	25.5	0	26.0	0	25.5	0
42"	26.0	0	26.0	0	26.5	0	25.5	0	25.5	0	26.0	0	25.5	0
48"	26.0	0	25.5	0	26.0	0	25.5	0	25.5	0	25.5	0	25.5	0
54"	--	0	25.0	0	25.5	0	25.0	0	25.0	0	--	0	--	0
60"	24.5	0	25.0	0	24.5	0	--	0	--	0	--	0	25.0	0

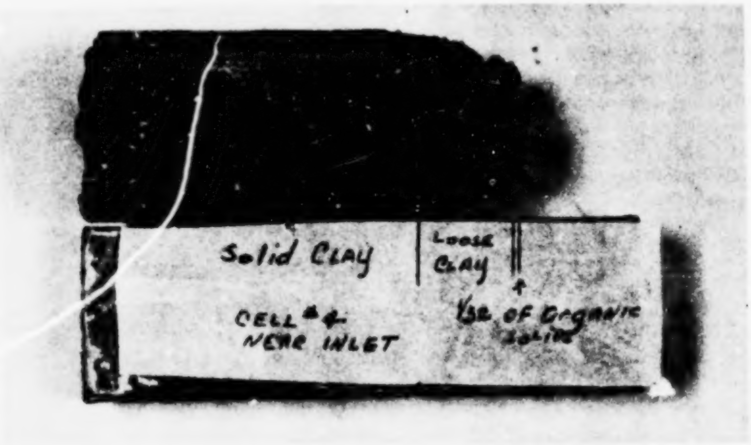
ODORS

Sulfides rose from ponds when oxygenless conditions persisted after disappearance of ice cover. Cell 2 returned to an aerobic state four days after its surface became open; Cells 1, 3, and 5 required 40 to 41 days; and Cell 4 remained oxygenless for 61 days after its ice melted. For a time in late February and early March, determination of units with greatest pungency was not possible, as sulfides were detactable for 550 feet from the general lagoon area and emanations from all cells were intermingled. By March 10, a noticeable decline in odor intensity was apparent and it was possible to follow the strongest sulfide trails to Cell 4. Release of malodorous gases gradually declined and Cell 4 had barely detectable odor for a few days prior to recurrence of oxygen therein on April 27. Decline in sulfides with prolonged oxygenless conditions has been assumed due to a low rate of photosynthesis that provides oxygen but in quantities unequal to demands. Oxygen absorbed from the atmosphere may also react with sulfide.

Odors did not extend to habitations or work areas.

BOTTOM DEPOSITS

Twenty-seven core samples, nine along each of three north-south transects at the 1/4, 1/2, and 3/4 points of the east-west width, were collected in each one-acre lagoon in May 1959. Terminal samples in each line were 10 feet from margins and others were at 20-feet intervals. Cores and supernatant water (2") were dried in sampler tubes for 12 hours at 100° C and stored in aluminum foil wrappings prior to measurement and study.



Each core (Figure 3) extended about two inches down into the original compacted clay bottom. The clay was covered with a layer of granular silt, and this stratum was topped by a thin, dark green coating of algae and organic matter. Details for each cell follow:

Cell	Loading (Lbs. BOD/Acre/Day)		Thickness (Inches)					
			Organic Layer			Silt Layer		
	1957-58	1958-59	Max	Min.	Ave.	Max.	Min.	Ave.
1	20	120	0.125	0.008	0.02	2.25	0.5	0.8
2	40	*	0.03	0.008	0.01	2.30	0.25	0.9
3	60	100	0.05	0.008	0.02	2.30	0.75	1.1
4	80	60**	0.02	0.008	0.03	2.40	0.25	0.7
5	100	60	0.06	0.008	0.02	2.25	0.4	1.1

*Received effluent from Cell 3. **5' deep.

Average thickness for the five lagoons was: organic layer 0.02 inch, silt layer 0.9 inch. Gray discoloration of lagoon water was common after heavy rains and it appears that infiltration into sewers was mainly responsible for the silt deposit, although dike erosion contributed some sediment before development of vegetative cover. Intermittent silting trapped some organic matter, and these inclusions are considered responsible for the granular nature of this bottom layer. The organic layers largely resulted from algal growth, in contact with the bottom and suspended in the lower two inches of water. It was deemed advisable to include suspended matter extending up this distance as it was impossible to distinguish between suspended and deposited particles. Flocculent matter often rose in large clouds when the bottom was disturbed. However, it dried to thin layers.

Cores were not assumed diagnostic of all events that had affected the bottoms. Yet, when Cell 1 was pumped down in October 1959, it was apparent that the core sampling pattern had given an accurate picture of the general sedimentation rate. It missed the small mound of silt at the orifice and the ridge along the inlet pipe (Figure 4), but these small areas were the only noted divergences from the general pattern. Broader inequalities in the bottom were left after final grading. Watered areas remaining in Cell 1 after pumping occupied essentially the same regions in which water first accumulated at the start of filling.

Loss of capacity occasioned by sedimentation of organic matter appears incapable of producing a criterical condition for a hundred years or more. Silting is a more serious matter and will probably result in a loss of one acre foot per surface acre in about 25 years.

Marginal and emergent vegetation, when allowed to remain a few weeks, added to organic bottom deposits in local areas; and mowers often allowed grass clippings to settle to the bottom over an area extending 2 to 4 feet from the waterline. These contributions were not included in core samples, as their presence was assumed unlikely with proper maintenance.

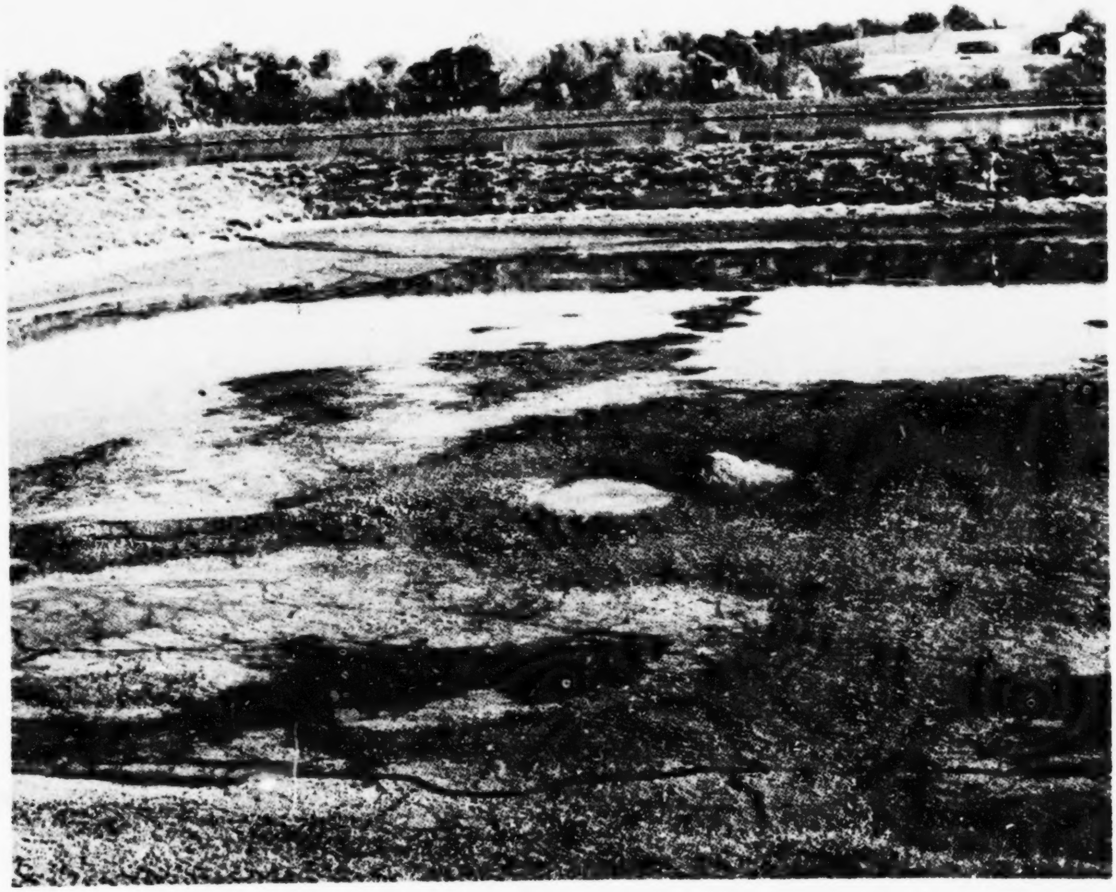


FIGURE 4 - Bottom of Cell 1, October 1959
Note mound of silt at end and silt ridge along inlet pipe.

SUMMARY

This article briefly reviews highlights of the 1957-58 investigation and presents 1958-59 findings. Operation was changed in June 1958 as follows: Load was increased to 100 and 120 pounds B. O. D./acre/day in Cells 3 and 1, respectively; load to units 4 and 5 was decreased to 60 pounds B. O. D./acre/day; and Cell 2 received only effluent from Cell 3. Depth was increased to 5 feet in Cell 4. Raw sewage load to Cell 6 fell to 8 pounds B. O. C./acre/day, and it continued to receive effluent from other cells.

Operations in 1958-59 substantiated earlier data in indicating desirability of in-series operation for realization of highest quality effluent and greatest assurance of oxygen production under ice and snow cover. Efficiencies in removal of various sewage components remained high.

Depth increase to 5 feet induced more prolonged thermal stratification and development of thicker anaerobic layers. The latter increased the likelihood of odor development as they could promote surface concentrations or sulfides when mixing developed with full circulation. Greater production of anaerobic compounds also delayed return of oxygen in the spring. Upward progression of wastes purification during periods of stratification, and aerobic cover then developed, would provide a simple in-series anaerobic-aerobic operation. However, a maintenance of this condition would require protection from wind with a transparent cover, and it appears to be slightly less efficient in B. O. D. and coliform removal then operation with more constant circulation and greater aerobic volume.

Bottom studies indicated inconsequential capacity loss to organic sedimentation. However, silting orginating in sewer infiltration will occasion a loss of one foot in each cell in 25 years.

REFERENCE

1. Neel, Joe K., McDermott, J. H., and Monday, C. A., Jr. "Experimental Lagooning of Raw Sewage. Fayette Missouri, Experimental Stabilization Ponds. 1957-58." (To appear in Journal, Water Pollution Control Federation.)

STABILIZATION POND RESEARCH AND INSTALLATION EXPERIENCES IN CALIFORNIA*

by

William J. Oswald**

INTRODUCTION

It is the purpose of this article to cover the status of stabilization pond utility and design in California and on the basis of current research to attempt to predict the trend that future pond development will take. Before entering a discussion of California ponds it is well to review certain factors which are common to all ponds, namely the physical and biological reactions which occur in them, their performance or waste treatment capability and their classification. This brief review is drawn, in part, from a more extensive discussion of pond design fundamentals presented elsewhere (6).

Physical and Biological Reactions. A list of evident physical and biological reactions in ponds must include with respect to the liquid, such properties as inflow, evaporation, percolation, overflow, thermal effects and gas exchanges, and with respect to organic matter; sedimentation, flotation biological oxidation, anaerobic acid decomposition, methane fermentation and photosynthesis.

The hydraulic properties of a pond are important because a hydromass of some magnitude is essential to sustain and protect the pond microorganisms from rapid changes in pH, temperature, gaseous tension and nutrient concentrations. Creation of a hydromass, therefore, is a prerequisite to establishment of a stable biological community. Not infrequently in newly activated ponds the volume of evaporation and percolation may approach that of the inflow and the pond contains so little water that marshy conditions sometimes prevail. Under these conditions opportunist algae such as Chlamydomonas undergo massive and useless proliferation, accumulate on the surface, and some die to become vilely odorous and to form a breeding place for gnats and flies. If the volume of inflow sufficiently exceeds evaporation and percolation the pond gains depth and ultimately comes to equilibrium or overflows. The quality of this overflow then becomes significant from a biological, bacteriological and public health standpoint. Inasmuch as both evaporation and percolation are expressed in inches per day, the hydraulic load on a pond is conveniently similarly measured. For example pond 48 inches deep, operating at a detention period of 12 days, receives an inflow of 48/12 or 4 inches per day. If evaporation and percolation total 1 inch per day, outflow will be 3 inches per day.

The allowable organic load on a pond is a function of the rate at which the various biological processes dispose of the load without nuisance and hence its magnitude is the sum of all such biological removal processes. The initial biological process, acting upon organic matter entering a pond, is usually biological oxidation. Biological oxidation is dependent upon the presence of suitable organisms, and sustained continuity of optimum pH (7 - 9), temperature 15° - 25° C, sufficient time to develop a stable population, the presence of oxygen 2 - 10 ppm. and the availability of organic matter. Of major concern is the availability of oxygen for which two sources need be considered--atmospheric reaeration and photosynthesis. Without special mixing of a pond by artificial or natural means atmospheric reaeration will introduce less than 40 lbs. of oxygen per acre per day even under anaerobic conditions. A pond

---

*This research was supported in part by research grant 2601 from the National Institutes of Health, United States Public Health Service.

**Associate Professor of Sanitary Engineering and Public Health, University of California, Berkeley, California

which operates without nuisance is of course aerobic and therefore absorbs less oxygen. Thus atmospheric reaeration contributes very slowly to the oxygen resources of unmixed ponds. In fact, atmospheric oxygen is often excluded by supersaturation conditions which accompany vigorous photosynthesis.

It has been shown that under satisfactory conditions of illumination, temperature and nutrition, photosynthesis may give rise to 200 lbs. of oxygen per acre per day. Assuming 3.68 calories per mg. of oxygen and a light conversion efficiency of 5 percent (7) the light energy requirement is 15,000 calories per liter per day, and intensity attainable in ponds 14 inches deep in summer and 4 inches deep in winter. Under present operational conditions these depths are impractical for many reasons. For example, under the conditions of oxygen production cited, a pH of 11 may be reached under which conditions, bacterial growth and oxygen utilization halt entirely, and coagulation and precipitation of the entire biomass may follow. A pond 4 feet deep receiving light equivalent to the 15,000 calories per liter per day cited above will produce about 50 lbs. of oxygen per acre per day with an increase in pH to 9.5. Thus successful pond designs are currently limited to load rates of 40 to 50 lbs. of BOD per acre per day. Extensive mixing facilities would be required to utilize the maximum photosynthetic oxygenation rate of 100 or 200 lbs. per acre per day because sedimentation maintains the biologically available organic matter at the pond bottom.

Biological flocculation accompanying biological oxidation brings about accumulation and sedimentation of most of the dissolved organic matter introduced into a pond within 24 hours. Studies have shown that the mass of this material may equal, or exceed, the applied BOD load. Thus, a pond loaded at 40 lbs. of 5-day BOD per acre per day will also have about 40 lbs. of volatile solids deposited at the bottom each day. Because of its concentration and position this material is no longer subject to aerobic oxidation. The fate of this organic matter at the pond bottom is then a function of the conditions existing at the pond bottom when it arrives.

Four major possibilities exist. First, the temperature is near 4° C, or if the pH is below 5.5, decomposition of the organic matter is very slow and heavy accumulations of organic matter become stored at the pond bottom. Second, if bottom temperature is high, acid decomposition occurs, and particularly in high sulfate waters sulfate reduction may occur with attendant hydrogen sulfide nuisance. The third possibility is methane fermentation which may be highly desirable for BOD removal. Ideally, methane fermentation requires a pH of 6.8 to 7.2, an absence of oxygen, relatively high temperature, available volatile acids, the essential organisms, and sufficient time for the process to become established. Under ideal conditions several hundred lbs. of organic matter per acre per day may be converted to methane. Methane fermentation is evidenced by widespread easily visible bubbles of gas rising to the quiescent pond surface. The normal ratio is believed to be 10 cubic feet of gas per pound of BOD destroyed. Acid conditions and low temperatures may delay or entirely inhibit the onset of methane fermentation, but if fermentation is in progress, acid conditions are less likely to occur because the products of acid decomposition are rapidly converted to methane. It is believed that methane fermentation blocks the occurrence of sulfate reduction, primarily because it controls the build-up of organic matter; one essential for sulfate reduction. Methane fermentation is a desirable process for decomposition of settled pond bottom deposits and, once the process is established, leads to a stable, low nuisance pond operation. There is little information on the rate of accumulation of stable sludge solids in ponds undergoing fermentation. At the Concord, California, ponds sludge accumulation amounted to about 1 or 2 cubic feet per annum per capita. Most of this deposition was within 200 feet of the pond inlet, a fact which demonstrates the rapid rate of sludge deposition in an active pond. The fourth possible fate of organic matter is to bring about its resuspension by physical means, accompanied by processes which furnish sufficient oxygen to permit aerobic decomposition.

Pond Classification. Based upon a recognition of the importance of several biological processes it has been proposed that from the treatment standpoint three major classes of ponds could be defined--an-aerobic, facultative, and aerobic (6).

Anaerobic ponds were defined as those in which the major fraction of the applied BOD is decomposed through methane fermentation. Designed to establish conditions which encourage methane fermentation, these ponds may be as much as 10 feet deep, have a small surface area to volume ratio and may be loaded in excess of 400 lbs. per acre per day. Anaerobic ponds may be extremely odorous and, therefore, must be carefully located with respect to populated areas. Effluents from anaerobic ponds usually have a BOD in excess of 200 ppm. and hence require further treatment before discharge into a water course. Photosynthetic bacteria have been observed to become established in anaerobic ponds. These organisms convert hydrogen sulfide to elemental sulfur and hence aid in the control of odors. If active sulfide reduction occurs, ponds may be without odor.

The term facultative was proposed for stabilization ponds most commonly described in the literature. Ideally, BOD removal occurs as a result of both aerobic processes occurring in the supernatant and anaerobic processes occurring in the bottom sludge layers. Loadings are ordinarily confined to 50 lbs. BOD per acre and effluents rarely have BOD's in excess of 30 ppm.

In aerobic ponds organic matter is decomposed solely through the mechanism of aerobic oxidation. The ponds are designed with a large surface area to volume ratio and oxygen is introduced by mechanical aeration or photosynthetic oxygenation. In the former case, provision is required for sludge removal and in the latter case, large quantities of algae are grown and may be removed through separation as a valuable by-product. If continuous mechanical movement of the liquid is employed BOD loadings in excess of 500 lbs. per acre are possible. If photosynthetic oxygenation is employed BOD loadings are 100 to 200 lbs. per acre per day. In either case, effluent BOD levels of 20 to 30 ppm. are obtained. If algae are separated by flocculation an effluent BOD of less than 10 ppm. may be obtained. The amount of algae produced may be 20 to 30 tons per acre per year.

CALIFORNIA INSTALLATIONS

History. It is uncertain when and where ponds were first used in California. With regard to industrial wastes, the beet sugar industry which entered the state near the turn of the century brought with it the practice of impounding wash and processing waste waters. Impounding of sanitary wastes occurred coincidentally. A small ponding installation at Bitterwater, San Benito County, California, was constructed about 1916 to receive oil pumping station wastes, waste boiler feed water, and domestic sewage. Preceded by a septic tank this pond operated successfully for 25 years without nuisance. According to Gillespie (2) the first municipal disposal plant utilizing ponds resulted from clogging of seepage beds at Santa Rosa, California in 1924. Gillespie's interest greatly accelerated the use and acceptance of ponds in California and throughout the West.

Distribution and Application. Ponds are now used throughout California and are distributed more or less uniformly in the intermediate population density areas of the state. There are about 125 (1) municipal stabilization ponds, perhaps three times as many industrial waste ponds, and numerous small pond installations in connection with niki bases, communication centers, isolated restaurants, motels, and so on.

Installations now exist which process raw sewage or wastes, screened and comminuted sewage or wastes, primary effluent, trickling filter effluent, activated sludge effluent, effluents from prolonged aeration tanks, imhoff tank effluent and septic tank effluent.

The ponds receive domestic sewage, beet sugar waste, fiberboard and plywood manufacturing wastes, miscellaneous fruit and vegetable wastes, vegetable dehydrating or freezing plant wastes, nut processing wastes, animal holding pen and feeding pen wastes; slaughter house, packing house, poultry processing and reduction plant wastes; and refinery wastes. As far as is known milk processing wastes and winery wastes are not processed in ponds in California.

Pond Systems. There is endless variation in the type of pond systems employed in the numerous installations and communities. Numbers of ponds in a given system vary from single ponds to some with a total of 10 ponds. The flow-through patterns for multiple ponds include series, parallel and combinations of the two. Many of the systems can be varied from series to parallel. Many systems have anaerobic and facultative ponds in series.

Types of Ponds. Many California ponds fall into the general class defined above as facultative. Other ponds are so shallow or lightly loaded that they remain aerobic through most of their depth. Several ponds are intentionally designed to operate in an anaerobic condition. A system of 4, 2-acre facultative ponds, operated in parallel, is to be found in the 8-acre experimental diversion system at Woodland, California. Loaded with raw, comminuted sewage at the rate of about 50 lbs. of 5-day BOD per acre per day, the ponds are anaerobic with methane production in the bottom deposits and aerobic with algal growth in the supernatant. Observed to be entirely nuisance-free, the ponds discharge no effluent and have attained an equilibrium depth of about 5 feet under a hydraulic load of 1.5 inches per day. Two recurring transcient phenomena periodically modify activity in these ponds. A periodic lightening from their characteristic green color usually follows a period of vigorous algal growth. This lightening is partially attributed to flocculation of algae accompanying precipitation of magnesium hydroxide and other salts under conditions of high pH and warm temperatures which typify periods of vigorous algal growth. Following precipitation a sharp decrease in dissolved oxygen is observed accenting the importance of photosynthetic oxygenation in such ponds. A second phenomena is recurrent infestation with "shrimps" and rotifers which also bring about precipitation of the algae and a lowering of the dissolved oxygen. According to Hiatt (3) dosage of the ponds with 1 - 2 ppm. of "Dibrom 8" (Ortho) has proved effective in controlling Daphnia at Woodland.

An interesting anaerobic stabilization pond is located at the Marks Reduction Plant, Woodland, California. Reported previously (6) this pond receives a summer BOD load of about 700 lbs. per acre per day and a hydraulic load of 2 inches per day. The effluent is discharged into a secondary pond where it leaches into the soil. The primary pond receives combined reduction plant waste and condensor water having a BOD of 1,000 to 1,600 ppm. The primary pond effluent has a BOD of about 200 ppm. The supernatant BOD in the secondary pond is about 50 ppm. Wastes in the primary pond undergo heavy methane fermentation. The pond's surface is deep pink with Thiopedia. The secondary pond is aerobic at its surface and deep green in color with Euglena. BOD removal in each pond is about 75 to 80 percent and over-all BOD removal is in excess of 90 per cent. Odors from the primary pond are largely controlled by the Thiopedia which utilize hydrosulfide. The secondary pond is odorless.

No prototype aerobic (high rate) ponds are to be found in California. Small scale pilot plant units, 0.01 acres, have been in operation at the University of California Field Station for a number of years and are believed to have amply demonstrated the utility of this process. These units receive 3 to 6 inches of hydraulic load and 100 to 200 lbs. of BOD load per acre per day.

BOD Loadings. Most California ponds are designed for BOD loads of 40 to 50 lbs. per acre per day but many exceptions exist. The lightest pond loading thus far encountered is at the U. S. Army Communications Center, Davis, California. About 3 feet deep in adobe soil, the pond has a detention period in excess of 60 days and a BOD loading of about 10 to 15 lbs. per acre per day. The pond is preceded by a conventional septic tank and is followed by a secondary pond which is fenced separately from the primary pond and serves as a watering place for several dozen sheep used to control vegetation among the radio antenna masts.

The most heavily loaded industrial waste pond is that described above at the Marks Reduction Plant. The most heavily loaded domestic waste pond in California is the primary pond at Concord. This primary pond has a flow-through channel about 1 mile long constructed of redwood baffles and has aggregate area of 14 acres. Its loading is about 250 lbs. per acre per day. Although able to sustain this load and remain odor-free in summer the pond "fails" and becomes odorous in winter. "Failure", however, merely means that hydrogen-sulfide odors are excessive at a nearby shopping center. Even during "failure" the pond discharges an effluent to the secondary pond with a BOD less than 70 ppm. The secondary pond has an area of about 15 acres and also is arranged by means of baffles for flow-through. This pond discharges an effluent BOD of about 30 ppm. to Walnut Creek. Recirculation from secondary to primary ponds is not possible under current design, but new construction will provide this feature which is strongly indicated under these circumstances.

Pond Sizes. In physical size the vegetable processing waste lagoons are largest. Examples are the Spreckles sugar waste lagoons, Woodland, 400 acres in several ponds; municipal and cannery waste facultative lagoon, Stockton, 200 acres in a single pond; and the municipal and cannery waste lagoons, Davis, about 100 acres in 10 ponds. Of the municipal waste ponds one of the largest is that at Chico in which, since no effluent is permitted in the receiving stream, evaporation and percolation must consume the entire sewage flow. The Chico ponds have an aggregate area of 103 acres, serving a population of 15,000. Following primary treatment, BOD loading on these ponds is about 1,200 lbs. per day. About one-third of the pond area is farmed each year, the farmed acreas being rotated; a feature which greatly improves percolation. Levees on a gentle alope of 8 or 10 to 1 permit cultivation of the entire pond area.

Another large municipal pond system is located at El Centro, California. Consisting of three ponds this system has an aggregate area of 50 acres, serving a population of 18,000. Following primary treatment, the BOD load is reported to be about 50 lbs. per acre per day (5). Relatively shallow depths, combined with large sized ponds, have lead to heavy algal growths which accumulate on the surface and decompose. An urgent problem with hydrogen sulfide odors in this pond's system was greatly improved as a result of a special study by Maloney et al. (4). By excluding milk waste, hydrogen sulfide odors were minimized but entirely satisfactory operation has not been attained to date. In current studies the ponds will be operated at a depth of 6 feet in an effort to overcome excessive algal growth and perhaps permit establishment of methane fermentation in bottom deposits.

The smallest pond installations are those to be found at road-house inns and individual homes in remote locations of California. The disposal system usually consists of a grease trap, a septic tank, and a pond sometimes hastily scooped out to replace a clogged leaching field. Although poorly maintained, one finds these simple little ponds green and odor-free.

Pond Depths and Bottom Shape. Excessive algal growth which leads to formation of mats, sometimes loosely termed "blue green algae" is an objectionable condition which may be prevented by using greater depth. The current trend in California is away from shallow depths for facultative ponds. High rate ponds, which are entirely dependent upon aerobic decomposition for waste disposal, must be shallow to permit photosynthetic oxygenation. Facultative ponds, however, which are dependent on both aerobic and anaerobic processes, should be designed to permit the occurrence of bottom conditions favorable to methane fermentation. Thus depths of 5 to 6 feet are implied. Anaerobic lagoons which depend almost entirely upon digestion for disposal have been designed with depths of 10 or 12 feet.

In a trend away from uniform depths several recently designed California ponds, such as those at Vacaville, are constructed with a gentle bottom slope leading to a drain. Stone (8) has recently described a pond with a center well which gives the pond a small collective area for low flow conditions.

Levee Slopes and Protection. A great variety of levee cross sections are to be found. The flattest levees known to the author are those at Chico, noted previously, with side slopes of about 10 to 1. No unusual operational problems have resulted from this extremely stable cross section. At the other extreme the City of Concord, pressed for area, has shaved its well compacted peripheral levees to slopes of less than 2 to 1 and abandoned internal levees entirely in favor of redwood fences, or baffles, used as flow guides. Experience has shown that care must be exercised to maintain approximately equal depths on either side of these fences to prevent failure.

A greater degree of levee protection from wave erosion is afforded by maintaining gentle levee slopes than by heavy compaction. Rigid compaction specifications add greatly to the cost of pond construction. Wind damage is decreased by decreasing pond size but even 1 or 2-acre ponds will suffer erosion of steep, carelessly compacted banks during strong winds. Linings have been used to protect steep levees.

Special bank protection installations are to be found at a number of places. Stockton has placed a coat of 6 inches to 8 inches riprap on its inner levee face. At El Centro all levees are lined with one-half inch prefabricated asphalt panels. Davis has complete asphalt caps on some levees with gunite side slopes. Both the riprap and asphalt panels cost about 30 cents per square foot in place. Cost data is not available on the concrete liners. At Lakeport, California, Trotter controlled excessive seepage with local clay spread and compacted over the entire pond bottom (9). The University of California's pilot stabilization pond at Concord was partially lined with 6 mil polyethylene. There are no reported cases of ponds completely lined with more expensive materials.

Inlet and Outlet Structure. Inlet structures have mainly consisted of simple risers located along one side, or in the center, of the pond. Several consulting engineers have installed inlets designed to discharge a horizontal tangential jet of sewage which appears to give rise to gentle sustained currents in the ponds. No special benefits have been observed to result from either jet type or riser type influent structures. Limited comparable experience has shown that the Woodland ponds, with submerged vertical central inlets, developed methane fermentation more quickly than did the Concord ponds which are equipped with tangential jet inlets. However, unknown factors other than inlet design could have produced this result.

Outlet structures are frequently simple wooden boxes, or corrugated metal culverts, placed in the levee at an invert height, corresponding to a selected depth. Vertical risers, built of metal or concrete and having flash boards with which to control depth, are commonly used. A modification of this type of outlet is a series of rings stacked in a ring guide. This latter device has the advantage of allowing 360° skimming and has been used on recirculation lines at Concord.

Types of Algae. Observation of algal type in many California ponds shows that the major algae are nearly always Chlorella, Scenedesmus, Euglena or Chlamydomonas. Ankistrodesmus and various blue-greens are frequently found but usually do not dominate. With regard to the four most common algae, Chlamydomonas is the least desirable, for although it can grow with explosive speed it spreads over pond surfaces, shuts out light, and accumulates in corners where it decomposes with vile odors. In Richmond, Euglena viridis has also been observed to form surface scums.

FUTURE DEVELOPMENTS IN CALIFORNIA PONDS

Currently the use of facultative ponds is increasing in California. As conventional municipal pond installations become more heavily loaded there will be a tendency in land short areas to undertake processes which will make more efficient use of available land. Under these conditions the facultative pond may not survive. It seems doubtful, however, that there will be a complete return to trickling filters and activated sludge plants since these processes, although they meet current state standards, produce, rather than remove, fertility elements. Regardless of their low BOD and bacteriological purity, effluents from activated sludge and trickling filter plants are understood to inevitably produce nuisance algal blooms of uncontrolled and ever-increasing magnitude in inland receiving waters. It is therefore expected that additional state standards for water pollution control will be forthcoming and that effluents which contain fertility elements will be judiciously excluded from receiving waters which have no discharge to the sea. Thus new processes must be developed which will not only remove BOD and decrease bacterial content, but also strip away ammonia, carbonate, phosphate, and other fertility compounds.

California's new inland reservoirs such as Turlock, Berryessa or Nacimiento are undergoing explosive development of population and recreational facilities. Sewage effluents, seepage pit effluents, and effluents from leaching fields, will inevitably carry fertility elements into these reservoirs in increasing amounts. Successive crops of algae will integrate these nutrients and bring about accelerated eutrophication. A large measure of the enormous recreational value of these reservoirs will eventually be lost, due to excessive algal growth. A sewage disposal process is required which will prevent this. The only process which appears economical for this purpose today is the high rate photosynthetic oxygenation pond.

Research is now underway to develop small pond installations for isolated areas which will remove fertility elements and dissipate or reclaim them. The best hope seems to be lined, series operated ponds, from which the tertiary effluents may be used for spray irrigation of harvested crops, for fish ponds, or for beautification ponds and fountains.

In the industrial and agricultural waste field, California is continuing a vigorous research program for reclamation of an ever larger fraction of these wastes for useful purposes. But before this goal is achieved, it is probable that anaerobic ponds will be used to a greater extent because of their convenience as well as low construction and maintenance costs.

It is hoped that eventually inland California communities will undertake to utilize aerobic high rate algae ponds for all agricultural and domestic wastes, moving eventually into production and sale of algae and reclaimed water. Under these conditions we may look for algae to become a basic raw material, comparable to lumber or corn; a source of industrial and agricultural chemicals and foods of many kinds.

SUMMARY

This article reviews the history, distribution and current application of stabilization ponds in California with emphasis on special design characteristics in specific installations.

Fundamental reactions occurring in ponds, pond classifications and pond performances are described and discussed.

Current research and development and prospects for future pond applications in California are outlined.

REFERENCES

1. Cornish, A., and Ward, Paul, California State Health Department, Berkeley. Private Communication (1960).

2. Gillespie, C. G. "Oxidation Ponds in California," Sewage Works Journal, 16, 740, (1944).

3. Hiatt, A. L., City Engineer, City of Woodland, Private Communication (1960).

4. Maloney, T. E., Bartsch, A. F., et al. "Study of Experimental Sewage Stabilization Ponds at El Centro, California," U. S. Department of Health, Education, and Welfare, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, (1959).

5. McKlintock, Len C., City Manager, City of El Centro, Private Communication, (1960).

6. Oswald, W. J. "Fundamental Factors in Stabilization Pond Design," No. 44, Conference on Biological Waste Treatment, Manhattan College, New York (1960).

7. Oswald, W. J. "Light Conversion Efficiency of Algae Grown in Sewage," Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, 86, SA4, 1, 71-95, (1960).

8. Stone, Ralph, "Waste Stabilization Basins for a District Sewage Treatment Plant," Civil Engineering, 30, 3, 158-159, (1960).

9. Trotter, Roy M., and Associates, Consulting Engineers, Berkeley, Private Communication (1960).

STUDY OF THE PERFORMANCE OF A SEWAGE STABILIZATION POND AT FARMVILLE, VIRGINIA

By

C. E. Cooley, and R. R. Jennings*

INTRODUCTION

Stream pollution control in Virginia dates from July 1, 1946, when the State Water Control Law became effective. Soon afterward a small but determined staff began work on this very complex problem. The first job was to notify all communities that discharged raw sewage into State waters that they should formulate pollution abatement programs in accordance with the Law.

The Town of Farmville is one of the communities that was so notified. It has a population of about 5,000 and lies in an agricultural belt in south central Virginia. There is little industry in the area, but a college with a student population of approximately 1,200 contributes to the Town's economy.

The Town had retained a consultant who estimated the cost of constructing a sewage collection system and a "conventional" primary treatment plant to be something over 1/2 million dollars. This was not considered economically feasible by the Town fathers. Starting in 1947 they were requested periodically to appear before the State Water Control Board, which administers the Law, to explain why the Board's requirements had not been met. The case continued to drag until finally, in the latter part of 1956, the Town advanced the proposal to use lagoons, or stabilization ponds, to treat the sewage.

It was finally agreed, after conferences and meetings between representatives of the Town, the State Health Department, and members of the Board's staff, that the Town would use a lagoon to treat the sewage from a portion of the town.

Lagoons had been used in Virginia for a number of years successfully to treat industrial wastes from textile plants, canneries, and slaughter houses. They had not been used for treating sewage, however, this being the first such installation proposed.

The Town therefore agreed to construct the proposed lagoon in such a way that the Board could most expeditiously observe and study its performance. After many delays, final plans were drawn and construction was completed. Finally, on November 21, 1958, raw sewage was pumped to the lagoons for the first time.

SCOPE OF THE STUDY

While planning and construction was underway, the staff was in the process of determining the scope of its proposed study. Considerable data was available regarding physical design of ponds, so the principal objective was to determine the maximum possible B.O.D. loading which could be used in this climate. However, we decided that we would collect as much data relating to their performance as possible, within the limitations of personnel, equipment, time and money available. In this connection, we are especially grateful to personnel of the U.S.P.H.S., who gave us much advice and encouragement in getting our study program set up and moving. Their help, stemming from experience, saved us a great many headaches, but not all of them.

Automatic equipment was installed to collect all samples, both of raw sewage and effluents, for chemical analyses. Manually collected samples were used for bacteriological and biological analyses.

---

* Engineer and Biologist respectively of State Water Control Board, Richmond, Va.

Preceding page blank

From previous studies by the U.S.P.H.S. and other states it was apparent that physical features such as sunlight, rain, wind, and other natural conditions play an important role in the successful operation of sewage lagoons. Therefore, automatic recording equipment was set up at the ponds to obtain data regarding solar radiation (sunlight), barometric pressure, relative humidity, air temperature, and precipitation. Apparatus was set up to measure the rate of evaporation. Although there was no recording equipment for wind velocity and direction, frequent visual observations of indicating meters are made. We had intended to install Canwisher electrodes in the ponds to measure and record dissolved oxygen, but we were unable to get the necessary equipment set up in time.

DESCRIPTION AND LOADING

The Town agreed to construct the lagoon with three cells of identical size. In the remainder of this paper they will be referred to as ponds A, B, and C, as shown in Figure 3. Statistics on the ponds are given in Table 16. Depth has been maintained at 3 feet, although the outlet structures are designed so the depth may be varied between 3 and 5 feet.

TABLE 16

Size and Volume of Ponds

Size of each pond, acres	1.4
Size of each pond, square feet	60,984
Depth, feet	3
Capacity, cubic feet	182,952
Capacity, gallons	1,372,140

The 1/6, 1/3, and 1/2 volume split was in effect from November 1958, when the ponds started operating, until September 5, 1959. On the latter date 1/4 of the volume was put into Ponds A and B in series, and 3/4 to C. On December 15, 1959, all flow was diverted to Pond A, in series with B and C.

The sewage splitter compartment*, for the first 7 months of this study, was so arranged that ponds A, B, and C received 1/6, 1/3, and 1/2 of the raw sewage flow, respectively, for anticipated B.O.D. loadings of 20, 40, and 60 lb. per acre per day, or a population equivalent of 120, 240, and 360 persons per day, respectively. However, the volume of the raw sewage did not come up to that expected from preliminary studies, averaging only 62,660 gpd to the ponds, about half that originally expected. While B.O.D. concentration was in the expected range, the total load averaged only 90 lb. per day, also about half that expected. Table 17 shows the various expected and actual load arrangements.

Table 18 shows the actual B.O.D. load in pounds per acre per day and in terms of equivalent population.

---

*The splitter compartment consists of a cylindrical compartment 6 ft. in diameter and 1 1/2 ft. high. The incoming sewer line rises 1 1/4 ft. vertically into the center of the compartment. Three (or more) gates may be dropped into the annular space between the riser and the outer wall of the compartment to proportion the flow to the three ponds.

FARMVILLE SEWAGE LAGOONS

FIGURE 3

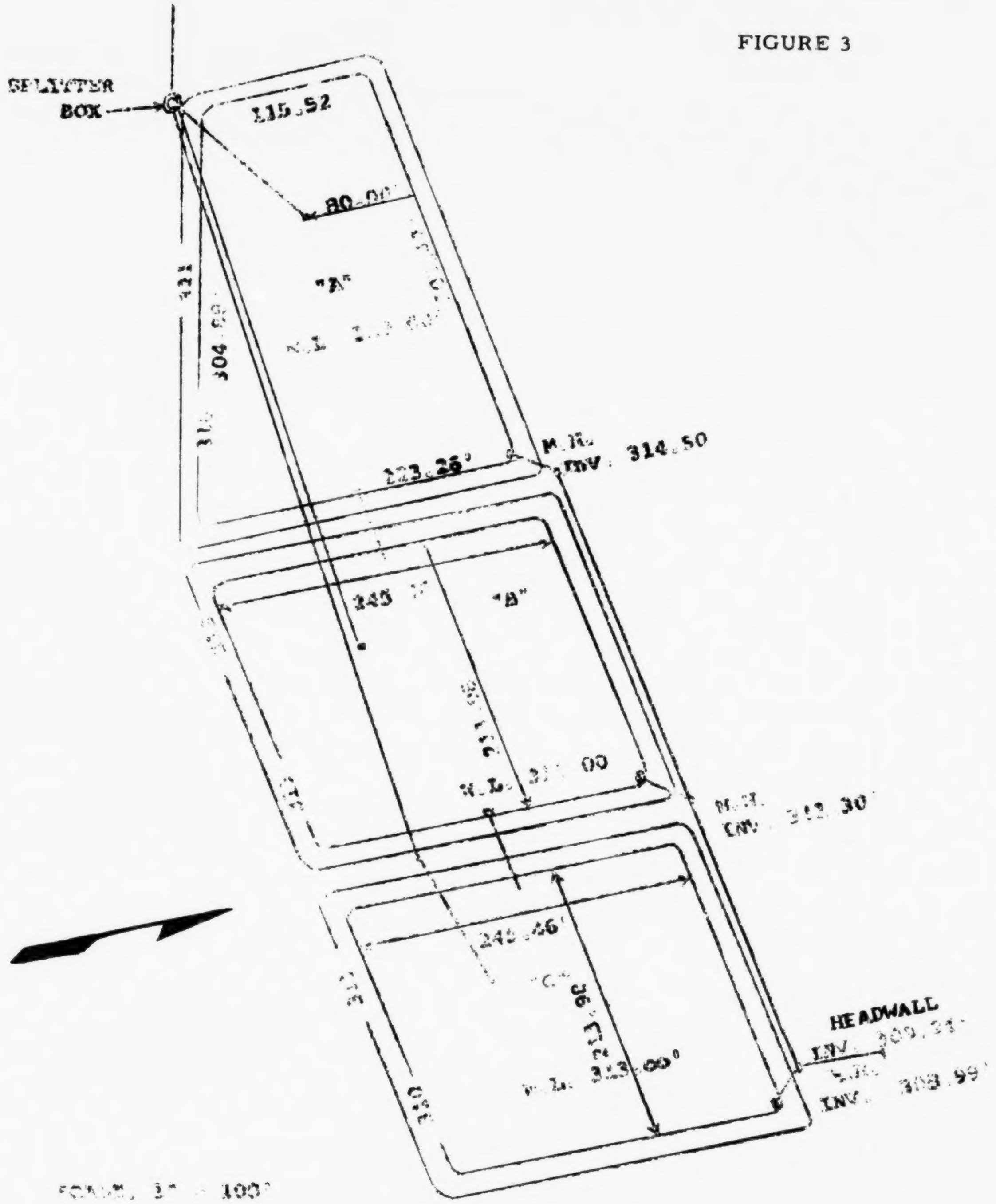

SPLITTER BOX
115.52
80.00'
"A"
421
304.00
318
223.26'
M.H.
INV. 314.50
245
"B"
211.88
W.L. 311.00
M.H.
INV. 312.30'
245.46'
"C"
213.96
W.L. 313.00'
HEADWALL
INV. 309.31'
M.H.
INV. 308.99'
SCALE 1" = 100'

FIGURE 3

TABLE 17

Volumes and Retention Periods

	Volume split: 1/6 to A; 1/3 to B; 1/2 to C				Volume split: 1/4 to A & B in series; 3/4 to C				Volume split: All to A, B & C in series			
	Design		Actual		Design		Actual		Design		Actual	
	Volume, gpd	Reten- tion, days	Volume, gpd	Reten- tion, days	Volume, gpd	Reten- tion, days	Volume, gpd	Reten- tion, days	Volume, gpd	Reten- tion, days	Volume, gpd	Reten- tion, days
Pond A	20,333	68	10,444	132	30,500	45	15,665	88	122,000	11	62,660	22
Pond B.........	40,667	34	20,888	66	30,500	45	15,665	88	122,000	11	62,660	22
Pond C.........	61,000	23	31,330	44	91,500	15	46,995	29	122,000	11	62,660	22
Total..........	122,000	--	62,660	--	122,000	--	62,660	--	122,000	--	62,660	--

The 1/6, 1/3, and 1/2 volume split was in effect from November 1958, when the ponds started operating, until September 5, 1959. On the latter date 1/4 of the volume was put into Ponds A and B in series, and 3/4 to C. On December 15, 1959, all flow was diverted to Pond A, in series with B and C.

TABLE 18

B.O.D. Load

	B.O.D., Lb. per Acre per Day	Equivalent Population per Acre per Day
Pond A (1/6 load)........	11	67
B (1/3 load)........	21	126
C (1/2 load)........	32	193
Pond A (1/4 load)........	16	96
B (series with A)		
C (3/4 load)........	48	290
Pond A (Total load)......	64	386

CHEMICAL AND BACTERIOLOGICAL EXAMINATION

Sampling

For chemical analyses, samples of the influent and final effluents from the ponds were taken with automatic samplers. During the first six months of this study (February to August, 1959) composite samples were taken every 12 hours, around the clock, of the raw sewage and of the final effluent from each pond. From August through October 1959 samples from the same sources were composited every 24 hours.

Samples were analyzed in a Water Control Board trailer laboratory stationed at Farmville. This trailer was equipped to make all necessary chemical and biological analysis. Chemical analyses made were pH, alkalinity, B.O.D., settleable solids total solids, total solids, suspended solids, ammonia, nitrite, mitrate, sulfate, phosphate and chloride.

Results of Chemical Analyses

B.O.D. B.O.D. of the raw waste to the three ponds fluctuated a great deal. We believe that part of the variation is due to the fact that a hospital which is connected to this system periodically discharges some type of toxic waste. We have not made a study to identify this waste, but we hope to do so.

There was no great degree of difference in the amount of B.O.D. reduction in each of the ponds. Changing the flow arrangement on September 5, 1959 so that pond C received what could be considered a shock load by increasing it by 1/4, apparently did not affect the degree of B.O.D. reduction.

On the basis of the results of the above loading it was decided, on December 15, 1959, to give pond A, which received 1/4 the total flow at that time, a severe shock load by increasing it by 3/4, that is, to receive all of the raw sewage flow. There was no apparent adverse effect, as shown by a number of surveys made since that time.

The overall average B.O.D. reduction for the period from March 1959 through October 1959 was 80% in each pond. This same degree of treatment is now being accomplished by Pond A with a population equivalent of almost 400 persons per acre per day. There is little additional B.O.D. reduction in Ponds B and C, in series with A.

Percentages of B.O.D. reduction cited above are based on the concentration of B.O.D. in ppm. When considered on the basis of a pounds per day B.O.D. load in the raw sewage and in the final effluents leaving the ponds, the indications are that the efficiency will be higher. This is probably due to seepage and other losses within the system making the amount of liquid being discharged from the ponds less than the amount which they receive.

Ammonia The overall average ammonia reduction in the 3 ponds for the entire period has been 80%. As in the case of the B.O.D., ammonia in the raw sewage had a fairly wide range of concentration, while concentration in the final effluents from the 3 ponds was, for all practical purposes, the same.

There was considerable variation between the 3 ponds in percentage reduction of ammonia during the early period of operation, but during the late spring and early summer the same pattern of concentration is shown in the final effluents from the 3 ponds. However, since the flow arrangement was changed on December 15, 1959, for Pond A to receive the total load, we are experiencing an average reduction of only about 65%. Pond B, in series with A, adds 22 days retention time, and gives an additional 30% removal for a total reduction of 95%. Pond C adds another 22 days retention time but apparently accomplishes no further reduction of the ammonia.

Nitrates There was very little nitrification in the ponds.

Sulfates The sulfate concentration, as can be seen in Figure 5, is highly variable and does not show any significant increase or reduction. Analysis of the treated drinking water at Farmville also indicates a variable sulfate concentration and does not follow any definite pattern of concentration.

Orthophosphates Orthophosphates show an apparent reduction within the ponds; the greater reduction occurring with the least load.

Chlorides Although the data is not shown, we have found that there is no significant increase or decrease of chloride concentration within the ponds.

D.O. and pH D.O. and pH analyses were made on samples of the final effluents during a number of 24-hour surveys. These samples were collected every hour during any given 24-hour survey. In general, the results tend to follow the typical diurnal variation of both D.O. and pH within the ponds. However, some results do not show the typical variation. For example, we have experienced a high D.O. at night when we would expect it to be very low, or at least on a decrease. There is no apparent explanation at this time for this non-typical variation.

We have made a few preliminary studies on the D.O. concentrations in the ponds proper. Our results, to date show that there is a difference in concentration at the various sampling stations established for this purpose. We hope to make further studies along this line.

Results of Bacteriological Analyses

Coliform reduction was 99% for at least 50% of the time and 90% or more for 99% of the time. MPN of coliform organisms in the raw sewage ranged from 4,000,000 to 110,000,000 plus.

BIOLOGICAL EXAMINATION

Introduction

This biological work covers only the microscopic phytoplankton and the aquatic insects which inhabit the Farmville stabilization ponds. To avoid confusion regarding which organisms comprise the phytoplankton and which comprise the zooplankton, all those planktonic forms of life which are autotrophic are considered as belonging to the group of organisms known as Algae.

Also to further simplify the classification of the Algae, the organisms as herein reported are broken down into three major groups, as follows:

Green Algae - Bear chromatophores, usually store their food in the form of starch, usually possess pyrenoids, and do not possess flagella in the adult stage. The diatoms are included within this group, although they do not store starch.

Bluegreen Algae - Do not bear chromatophores, the pigment being distributed throughout the cytoplasm; do not store their food in the form of starch; pyrenoids are lacking; and do not possess flagella.

The Flagellates - Possess flagella during the adult stage of their life cycle.

Technical Methods

Sampling From May 1959 through July 1959 all samples collected for biological determinations were made on the final effluents of the three ponds. This was done on the assumption that an equal distribution of organisms existed. Early in the study only one final effluent sample per pond was collected for any particular 24-hour period, but in some cases the time of collection differed.

To ascertain if we were obtaining a representative phytoplanktonic flora, samples were collected of the final effluents at dawn, midday, dusk, and midnight. The results indicated that not only were different genera discharged during the periods in question but also that their concentrations varied. Sampling stations were then selected in the ponds proper. Results showed an unequal distribution of genera and numbers within genera. Therefore, from August 1959 through December 1959, samples were collected in each pond proper, using a Foerst stream sampler. The samples thus collected, contained organisms from the surface down to a depth of 18". Four stations were selected in each pond. The above method, we believe, has given us a more representative picture of the flora in question.

The genera and the number of genera as herein reported are the total different genera as found at the four stations. The number of organisms, as reported, are the averages as found at the selected locations.

Enumeration The Palmer Cell, developed by Dr. C. M. Palmer, was used in counting the organisms. We believe that the method as put forth by Dr. Palmer is the most accurate devised to date.

Correlation of Biological and Chemical Results

The main purpose of the biological study was to determine if a correlation existed between the biological and chemical data.

Tables 19 through 22 set forth the results of the various possible relationships that were studied.

TABLE 19

Effect of B.O.D. Loading Upon the Number of Genera and the Total Number of Organisms

Date	B.O.D. Loading (lbs)	No. of Genera	No. of Organisms/ML (10^6)
Sept. 4, 1959...	17	25	.75
Aug. 28, 1959...	17	22	1.09
Sept. 18, 1959..	22	16	1.41
Sept. 4, 1959...	33	18	0.13
Aug. 28, 1959...	34	28	0.28
Sept. 4, 1959...	50	16	0.29
Aug. 28, 1959...	51	12	1.52
Sept. 18, 1959..	65	15	1.37
Sept. 11, 1959..	68	21	1.67
Dec. 14, 1959...	72	12	6.53
Oct. 20, 1959...	73	16	2.66

On the basis of the data we have obtained, we have not been able to demonstrate a correlation between the number of genera present, the total number of organisms and B.O.D. loading.

TABLE 20

Effect of B.O.D. Loading on the Predominant Genus Present

Date	B.O.D. Loading (lbs)	Predominant Genus
Sept. 4, 1959..........	17	Synectocystis
Aug. 28, 1959..........	17	Synectocystis
Sept. 18, 1959.........	22	Ankistrodesmus
Sept. 4, 1959..........	33	Synectocystis
Aug. 28, 1959..........	34	Synectocystis
Sept. 4, 1959..........	50	Synectocystis
Aug. 28, 1959..........	51	Synectocystis
Sept. 18, 1959.........	65	Synectocystis
Sept. 11, 1959.........	68	Merismopedia
Dec. 14, 1959..........	72	Ankistrodesmus
Oct. 20, 1959..........	73	Ankistrodesmus

There appears to be no correlation between the loading in terms of B.O.D. and the predominant genus. It might be noted that Ankistrodesmus, when not the predominant genus contributed greatly to the total number of organisms.

TABLE 21

Percent Reduction in B.O.D. Compared to the Predominant Genus at Different Loadings

Date	Predominant Genus	B.O.D. (lbs) Load	Percent Reduction
Sept. 4, 1959	Synectocystis	17	80
Aug. 28, 1959	Synectocystis	17	79
Sept. 18, 1959	Ankistrodesmus	22	79
Sept. 4, 1959	Synectocystis	33	80
Aug. 28, 1959	Synectocystis	34	78
Sept. 4, 1959	Synectocystis	50	79
Aug. 28, 1959	Synectocystis	51	16
Sept. 18, 1959	Synectocystis	65	78
Sept. 11, 1959	Merismopedia	68	79
Dec. 19, 1959	Ankistrodesmus	72	84
Oct. 20, 1959	Ankistrodesmus	73	49

As in the two previous cases, there appears to be no correlation between the percent reduction and any particular predominant genus.

TABLE 22

Percent Reduction in B.O.D. Compared to the Number of Genera and the Total No. of Organisms At Different Load Levels

Date	B.O.D. (lbs)	No. of Genera	No. of Organisms/ML (10^6)	Percent Reduction
Sept. 4, 1959	17	25	0.75	80
Aug. 28, 1959	17	22	1.09	79
Sept. 18, 1959	22	16	1.41	79
Sept. 4, 1959	33	18	0.13	80
Aug. 28, 1959	34	29	0.28	78
Sept. 4, 1959	50	16	0.29	79
Aug. 28, 1959	51	12	1.52	16
Sept. 18, 1959	65	15	1.37	78
Sept. 11, 1959	68	21	1.67	79
Dec. 14, 1959	72	16	2.66	84
Oct. 20, 1959	73	12	6.53	49

Again, as far as we can determine at this time, there appears to be no correlation of biological and chemical results.

Typical Genera

Below are listed some typical genera found in the Farmville ponds.

GREENS

- Ankistrodesmus
- Chlorella
- Chlorocooccum
- Closterioposis
- Coelastrum
- Cruglgenia
- Golenkinia
- Kirchneriella
- Micractinium
- Mavicular
- Nitzschia
- Oocystis
- Phytoconis
- Scenedesmus
- Schroderia
- Ulothrix

BLUEGREENS

- Anabaena
- Anacystis
- Merismopedia
- Oscillatoria
- Synectocystis

FLAGELLATES

- Chlamydomonas
- Chlorogonium
- Chromulina
- Cryptomonus
- Eudorina
- Euglena
- Glenodinium
- Gonlum
- Gyrodinium
- Massertia
- Pandorina
- Phagus
- Trachelomonas

Aquatic Insects

The field work incidental to this phase of the study was conducted by Mr. Jack Lamb, Entomologist, Virginia State Department of Health. The data is limited, since the main objective was to determine the principal aquatic insects inhabiting the ponds.

Listed below are the groups found:

- *Coleoptera*
  - Cyrindae (Whirligig bettles)
  - Dytscidae (Preddceous Diving Beetles)
  - Hydrophildae (Water Scavenger Beetles)
- *Hemiptera*
  - Notonectidae (Back swimmers)
- *Diptera*
  - Tendlpedidae (Midges)
  - Cullcidae
    - Chaoboninae (Phontom Midge)
    - Cullcinae (True Mosquitoes)
      - *Culex Piplens*
      - *Culex Salinarius*

Culex Piplens and *Culex Salinarius* were not found in the ponds proper, but were found both in the overflow line and in the bottom of one of the overflow boxes, when the discharge ceased due to evaporation. These creatures were also found inhabiting the effluent channel and the swampy area which receives some of the treated waste. Excluding the mosquitoes, the rest of the aquatic insects listed above were found in all three ponds at various concentrations, some in the effluent ditch, and some in the swampy area.

GENERAL OBSERVATIONS

Odor

Since the possibility of odors occurring is frequently thought of in connection with this type of treatment, we have paid special attention to this aspect of the sewage lagoons. Daily observations from February through September 1959, and frequent observations since September revealed no noticeable odors at a distance of more than 20 feet away from the ponds, except for one day, which was exceptionally hot and humid with negligible air movement, when odors were noticeable about 250 feet away.

Ice Cover

We have not experienced any difficulties in the ponds, either in the way of odors or treatment, due to icing.

During the two winters (1958-59 and 1959-60) that the ponds have been in operation, the ice cover has existed for only a few consecutive days at a time. Since there were so few days of continuous ice cover, we have not considered this condition a significant factor in our studies at Farmville. The 1958-59 winter was a particularly severe one.

Weather

Although we have voluminous data concerning the various aspects of climatology we have not yet had the time to correlate it with treatment within the ponds. We can, however, confirm the correlation that others have reported to exist between the solar intensity and dissolved oxygen within the ponds, that is, the greater the solar radiation, the greater is the concentration of dissolved oxygen that may be expected.

It is not apparent from our D. O. and pH studies that wind action adds any appreciable amount of oxygen to the ponds themselves. During our 24-hour surveys when there was sufficient wind to cause waves on the ponds, there did not seem to be any noticeable increase in dissolved oxygen. This may be due to the fact that the waves rolled rather than broke.

CONCLUSIONS

From the results of our studies the State Department of Health and the staff of the State Water Control Board have agreed that sewage lagoons with loadings of 200 persons (33 lbs. B. O. D.) per acre per day will be approved. This compares with an interim figure of 150, based on recommendations by the USPHS and various other agencies. Any further upward revision will depend on the evaluation of the data now being obtained in the current arrangement of the ponds.

Also, on the basis of these results, the interim requirement that ponds be located 1/2 mile from municipal limits and 1/4 mile from the nearest residence and habitation have been eliminated, and criteria used in setting distance requirements for conventional sewage plants will apply.

Though the coliform organism reduction was 90 to 99%, this still represents a high number of organisms being discharged to the receiving body of water. Chlorination, and perhaps also means for removing algae, must be provided where demanded by the uses of receiving stream.

Up to this point in our study we have not been able to correlate our biological data with the chemical analyses. In the future, after more data has been collected and compiled, we will again attempt to determine if a correlation exists between the biological and chemical aspects of the study.

Based on our study of the performance of Farmville, Virginia, sewage stabilization pond and our previous experiences with ponds treating industrial wastes, we believe that this method provides an entirely satisfactory and economical means for waste treatment, under conditions where it may be employed.

We have not had the time to tabulate and process much of the data that was collected. When this is done, additional conclusions and observations will undoubtedly be possible.

SEWAGE LAGOONS IN AUSTRALIA

by C. D. Parker*

1.0 Introduction.

Study of the possibilities of treatment of sewage in lagoons in Australia by the Melbourne and Metropolitan Board of Works goes back over 20 years and large scale application of this form of treatment has been in use there almost fifteen years.

With the amount of study that has been made of this form of treatment at Melbourne over the years it is not surprising that Melbourne offers the most extensive development of lagoons in Australia.

It is only over the last 5 - 10 years that there has been any other developments in Australia of lagoon treatment but now as in America, interest in the use of lagoon treatment is widespread, a number of installations have been built and some of the other larger authorities are now contemplating this form of treatment for sewage purification.

2.0 Australian installations.

2.1 Melbourne.

The use of sewage lagoons in Melbourne goes back twenty four years to 1936 when a large area of 570 acres was converted to a huge pond to give finalizing treatment to effluents from grass areas.

To understand the way in which development of sewage lagoons has occurred in Melbourne, it is desirable to briefly outline the methods of purification that have been used.

The Melbourne sewage system was constructed in 1893 on the separate principle and all flow gravitates to Spotswood Pumping Station 5 miles from the center of the city where it is at present lifted through rising mains 2 miles to the head of an 11" diameter gravity sewer which conveys the 110 m.g.d. (U.S.) to the Metropolitan Farm at Werribee.

The Farm is 27,000 acres in area and here the sewage is treated on 12,000 acres of pasture 2,100 acres of grass filtration area (used in winter) and 1,100 acres of lagoons.

Prior to the development of lagoons, sewage was purified in summer by irrigation over prepared pastures irrigated one day every 18 - 21 days and grazed by some 15,000 head of cattle and in winter by continuous surface application to grass areas, the effluent being taken into shallow collecting drains at the end of each bay.

Both processes are liable to disturbance by sudden increases in flow.

This is a daily problem with the natural fluctuation in flow over the 24 hours of the day. It is accentuated by the fact that the daily peak flows arrive at Werribee between midnight and 6 a.m. when distribution has to be made under night shift conditions.

The problem is further accentuated by storm flows when the daily flow arriving at Werribee is increased from 110 to 170 m.g.d. When these flows occur in summer and the pastures are sodden, it is a problem to dispose of the water.

In 1939 research into the possibilities of lagoon treatment was initiated using the installation described in our paper of 1950 (Parker et al S.W.J. 1950). This con-

---

*Chief Chemist and Bacteriologist, Melbourne and Metropolitan Board of Works, Aust.

Preceding page blank

sisted of a number of ponds with a total area of some 5 acres. The most important finding of these earlier investigations was the greatly increased efficiency achieved by using a two stage process, the first stage functioning as an anaerobic lagoon and the second stage the normal aerobic algal type lagoon. Other important operational factors were also established.

The large 570 acre lagoon already existing was adapted in 1947 to treat settled sewage in excess of the average daily rate of flow, over the daily night peak periods already mentioned. This development was based on the experimental work published in 1950. At first a 30 acre semi-land locked section served as an anaerobic lagoon but subsequently the overall capacity was increased by the provision of 50 and then a further 50 acres of prepared anaerobic lagoon, in conjunction with the 570 acre aerobic area. In 1951, the 115E lagoon of 60 acres, 15 acres anaerobic and 45 acres aerobic lagoon was built as a prototype anaerobic-aerobic installation also to treat these daily night peak flows. With increasing daily dry weather flow these units have increasingly been used for dry weather flows throughout the day. At present a third (35-40 m.g.d.) of the total flow is treated through these lagoons.

With present conditions it is possible to handle most of the extra storm flows through these lagoons by loading them below their maximum capacity under dry weather conditions and then increasing the flow of weak sewage. Thus the Murtcaim lagoon normally can handle 30 m.g.d. in summer and this can be increased to 50 m.g.d. for periods of two to three days.

A number of smaller areas amounting to 200 acres in all have been converted from fairly useless land areas to lagoons.

In Melbourne we are faced with an unusual situation in the next twelve months. The existing Spotswood pumping station is currently being replaced by a new station at Brooklyn situated at the head of the existing gravity sewer to Werribee. The sewage will be carried on from Spotswood to Brooklyn by deep tunnel gravity sewer and then lifted vertically into the gravity sewer. The new station will have a capacity of 300 m.g.d. compared with the present capacity of 170 m.g.d. Consequently as soon as the new station operates it will, under flood flow, pump 300 m.g.d. to Werribee instead of the present 170 m.g.d. This sudden increase in flow to be handled represents a considerable problem.

To cope with it an area of holding lagoons of over 400 acres (capacity 500 m.g.) has already been prepared and this can be increased if necessary.

Flood flows will then be run into these units and held until purified. They also provide some additional capacity for treating normal daily flows.

At Braeside Treatment Works lagoons are used in a different way. In building the original plant to serve an area at the southeast of the city, lagoons were provided following the trickling filters and humus tank. These consisted of two in series of about 1 acre in area, followed by a larger pond of 15 acres. The description of this installation was given in our paper (Parker et al, S.I.W. Journal 1959). With increasing flows these lagoons have successfully treated effluent from filters loaded at 1500 galls/c.yd./d (effluent B.O.D. 70 - 80 p.p.m.).

When the plant was enlarged to cope with the present contributory population of 27,000 the same principle was adopted. The new filters are now loaded at 850 galls/yd/d. the humus tank effluent has a B.O.D. 25 - 30 p.p.m. and this passes through two new lagoons of 3 acres each before discharging to the original 15 acre pond. In this way B.O.D. is brought down to 5 - 10 p.p.m. and the algal content is quite low, the suspended solids content remaining well below 30 p.p.m. at all times.

2.2 Kerang.

The lagoon installation here was built to meet a rather unusual condition and to treat sewage of unusual constitution. Kerang is a Victorian country town with population of 4 - 5,000. It is an irrigation area with a ground water level near the surface. As a result the sewer pipes are constantly immersed in ground water and subject to considerable infiltration. The ground water is extremely saline containing some 60,000 p.p.m. total mineral solids. The sewage is consequently highly mineralized and low in B.O.D.

The wooden rising main which conveyed the sewage to the treatment plant had become so filled with slime growth that it was only possible to pump the flow part way to the treatment plant and release it into a swamp. Through lack of use the treatment plant had fallen into disrepair and when the main was cleared by lime and chlorine treatment, it was decided rather than repair the old plant to treat the sewage in lagoons. During the time when the sewage was discharged to the swamp a considerable odour nuisance existed and this was a further reason for taking remedial measures.

The lagoon was constructed as two anaerobic ponds in parallel followed by a larger aerobic unit. The daily flow was 500,000 galls/day, the two anaerobic units were 0.2 acres each and the aerobic unit 2.0 acres. The detention time allowed was only 16 hours in the anaerobic unit. Operation of this installation has shown some rather unexpected results. Presumably because of the high mineral content, growth of sulphate reducing vibrios in the anaerobic unit has been extraordinarily prolific in the 16 hours detention there is an increase to 20 - 30 p.p.m. sulphide in the effluent. This in turn imposes an additional oxygen demand on the aerobic unit and it is remarkable that in the 30 hours detention in the aerobic unit this sulphide is wholly destroyed and the B.O.D. is reduced to 25 - 30 p.p.m. a slightly longer detention in the arm of the swamp to which the effluent discharges brings the B.O.D. well below 20 p.p.m. The microbiology of this installation offers a fascinating field for study but owing to the distance from Melbourne it has not been possible to do much about it. Certainly the algal development in this highly saline lagoon is very different from the normal growth.

Probably the most effective way of dealing with this type of sewage is a single large aerobic lagoon with recirculation of effluent to the influent to prevent the development of anaerobic conditions.

2.3 Wangaratta.

Here the domestic sewage from a town of 5 - 6,000 together with woollen mill and rayon weaving mill wastes are treated in an anaerobic unit of 3 acres with 7 days detention and an aerobic unit of 20 acres with 22 days detention.

The aerobic lagoon is a typical single unit pond with profuse growth of Euglena and Trachelomonas, the filtered B.O.D. is 10-15 p.p.m. It is at present proposed to subdivide the 20 acre aerobic pond into a series of small units to be operated in series to reduce the algal content of the final effluent.

2.4 Castlemaine.

Here lagoons are provided after trickling filters, there is ample detention and a sparkling clear algal-free effluent is obtained.

2.5 Commonwealth Department of Works.

Has a four lagoon installation, as tertiary treatment for overloaded filter plants.

2.6 Others.

A few other country sewage treatment plants have lagoons after secondary treatment.

3.0 Operational factors important under Australian conditions (Melbourne).

Use of sewage lagoons in Australia falls into three categories.

(a) Anaerobic - aerobic two stage units for the continuous treatment of dry weather flow raw sewage.

(b) Holding ponds for intermittent treatment of storm flows.

(c) Aerobic units for tertiary treatment after high rate trickling filters.

3.11 Anaerobic units - continuous treatment.

(a) There is no exact quantitative data as to whether they should be designed on an area or volume basis. Probably for the same volumetric content a shallower unit would be more effective than a deeper one.

(b) There is no optimum size as wave action is unimportant.

(c) With multiple cells these are more efficient if arranged in parallel.

(d) Their microbiological function is to perform a methane fermentation; photosynthetic purple sulphur bacteria are sometimes present but not algae. Sulphides are formed from sulphate but also destroyed, concentrations are often less in the effluent than the influent. There should be a rise of about 0.5 pH unit through the ponds.

(e) There is less odour than from a corresponding area of raw sewage.

(f) With high solids loading there is some carry-over to aerobic units but no evidence of failure of anaerobic units due to solids accumulation. Arrangement of anaerobic cells in series will minimize this carry-over. Possibly a sedimentation unit between anaerobic and aerobic units would be desirable.

(g) B.O.D. removals found are summer (70° F) 1200 lbs/ac/d, winter (48° F) 350 lbs/ac/d. Suspended solids are reduced from 450 p.p.m. to 75 p.p.m.

3.12 Aerobic units - continuous treatment.

(a) It is desirable to limit the size of each cell to 10 acres.

(b) Optimum depth is 2 - 3 feet.

(c) Pond Layout influences microbiological character of final effluent.

(d) B.O.D. removals are similar to elsewhere, 60 - 100 lbs/ac/d.

(e) Optimum ratio between area of anaerobic and aerobic units is 1 to 5.

(f) Wall construction may be 1 1/2 to 1 protected by concrete or 5 to 1 grassed or metalled.

3.2 Holding ponds for storm flow treatment intermittently.

(a) B.O.D. removal is at same rate as aerobic ponds operated continuously.

(b) Method of operation is dependent on hydraulic considerations, e.g. whether ponds should be held full, empty or half-full between uses.

(c) Where ponds are to be used infrequently deeper ponds are preferable to shallower units.

3.3 Aerobic ponds after high rate trickling filters.

(a) These may be used where complete odour elimination is necessary to relieve an overloaded filter plant or deliberately as a form of economic high rate treatment.

(b) B.O.D. removals are higher than for aerobic units treating raw sewage or anaerobic effluents

(c) The algal content of the effluent is low.

(d) High coliform removals are achieved.

4.0 Research.

Research in Australia on lagoon treatment is centred at the Melbourne and Metropolitan Board of Works.

The current program of research on lagoon treatment in Melbourne includes the following topics.

(a) The study of the effect of lagoon layout in relation to hydraulic characteristics of installations used for intermittent treatment of weak storm flows.

(b) Effect of various lagoon layouts on the chemical and microbiological characteristics of aerobic lagoon effluents loaded at the same over-all rate.

(c) Study of the most effective distribution of loading between high rate filters and lagoons when used in conjunction, particularly with regard to the chemical and microbiological characteristics of the final effluent.

(d) A comparative study of the microbiology of sewage lagoons operated in various ways.

ECONOMICS OF WASTE STABILIZATION LAGOONS IN REGION VI

By Herbert C. Clare and Daniel J. Weiner*

INTRODUCTION

The wider acceptance of the waste stabilization lagoon in the past decade reflects satisfaction of a demand by municipalities for a treatment facility which fulfills low cost as well as effective treatment requirements. In this period, an increased use of the lagoon for treatment of raw sewage has served to provide sufficient data to enable water pollution agencies, other interested agencies and individuals to provide more realistic fiscal data whenever the familiar question "How much is it going to cost?" arises.

Both raw sewage lagoons and conventional treatment plants have their places in the waste treatment field, and frequently conventional plants and waste stabilization lagoons have been utilized in combination to maintain the quality of water in a receiving stream.

The collection of extensive data for this report has been made possible by the passage of the Federal Water Pollution Control Act, P. L. 660, 84th Congress, wherein the U. S. Congress authorized grant funds for the construction of sewage treatment works as an integral part of Federal financial assistance for the prevention and control of water pollution. The intent of the Act is to "accelerate local programs of treatment works construction by providing an incentive to take action now to clean up the waters of the country".

STUDY METHOD

(a) Sampling

The acceleration of community programs to construct treatment works for the abatement and control of water pollution is reflected in some 452 projects, which have been completed or are in the construction or final planning phases, in Region VI, consisting of the states of Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota and South Dakota. Cost data have been assembled, and include either the final construction costs or the actual contract prices, depending upon the status of the project. The project design population equivalents range from 150 to 48,000.

For this presentation there have been gathered cost data from the files of 262 engineered treatment plants, which include: 13 primary plants, 81 secondary plants, 8 oxidation ponds (conventional treatment plants followed by lagoons), and 160 waste stabilization lagoons otherwise known as raw sewage lagoons. In Region VI there has been considerable activity in waste stabilization lagoon construction, indicated in Table No. 23.

Resonably accurate cost data are desirable, so that they can be used by water pollution control agencies, consulting engineers, municipal officials, and other agencies and individuals interested in water pollution control as a yardstick to gauge a municipality's ability to afford a waste treatment facility. Further, they help provide guidance in the selection of a particular type of works tailored to meet specific treatment requirements.

No attempt was made to evaluate differences in costs due to variations in design criteria for conventional treatment plants throughout Region VI. Similarly, there was no differentiation between lagoon loading and sizing; single or multiple cells; earthwork and land costs.

(b) Study Basis

This study was based on a comparison of hydraulic and organic loading and project cost. The loadings were those stated

---

*Respectively, Regional Program Director and Construction Program Director, Water Supply and Pollution Control Program, PHS, Region VI, Kansas City, Mo.

TABLE 23

Sewage Treatment Facilities

State	Primary Plants	Secondary Plants	Oxidation Ponds	Waste Stabilization Lagoons
Iowa................	2	21	--	3
Kansas..............	2	24	8	11
Minnesota...........	1	19	--	3
Missouri............	1	7	--	44
Nebraska............	6	10	--	21
North Dakota........	--	--	--	52
South Dakota........	1	--	--	26
Total............	13	81	8	160

by the consulting engineers. Included were the 20-year design factors, such as population and industrial growth. Estimates of future industrial wastes as presented in engineering reports were included in the design population equivalent.

(c) Statistical Method

To present the data statistically in linear form, the least squares method was utilized. This method is based upon the law of chance of random sampling and is designed to make the sum of the squares of the differences, or residuals, between observed and calculated values a minimum.

The least squares line for a given series may be obtained through use of a given set of "normal" equations. The "normal" equations for a linear equation, $y = a + bx$, are as follows:

(1) $a + b\frac{(Ex)}{n} - \frac{Ey}{n} = 0$

(2) $a\frac{(Ex)}{n} + b\frac{(Ex^2)}{n} - \frac{(Exy)}{n} = 0$

The range of data led to a use of the logarithmic scales, and "normal" equations for the linear form of the equation $y = ax^b$ were as follows:

(1) $a + b\frac{(E \log x)}{n} - \frac{E(\log y)}{n} = 0$

(2) $a\frac{(E \log x)}{n} + b\frac{(E \log^2 x)}{n} - \frac{(E \log x \log y)}{n} = 0$

Where Ex = sum of population equivalent (PE)
= sum of 1000 gpd design flow

Ey = sum of cost of treatment in \$/PE
= sum of hydraulic loading treated in \$1000/mgd

$E\log^2 x$ = sum of squares log population equivalent
= sum of squares log design hydraulic loading

$E(\log x)(\log y)$ = sum of products of the logarithms of "x" and "y"

a = constant

b = constant

Data are expressed in current dollar values for cost of treatment in \$/PE and in \$1000/mgd to provide realistic data based upon current dollar values for use of consulting engineers, municipal officials and others interested in treatment costs. Comparisons with other known methods and indices were considered.

TREATMENT COSTS

Total costs, including land costs, based upon the total population equivalent to be treated and the total design flow, are included in Table No. 24.

Primary treatment installations would serve a population equivalent of 186,760 with a flow of 19.31 mgd, at a cost of \$3,530,830.88.

TABLE 24

Total Design Loadings and Costs

Conventional plants	Design population equivalent	Design flow 1000 gpd	Total cost (dollars)
Primary..........................	14,366	19,313	3,530,344.88
Secondary........................	414,466	36,550	14,300,972.01
Oxidation Ponds..................	4,800	491	308,550.32
Lagoons including interceptors.....	291,570	28,049	8,044,830.34
Lagoons excluding interceptors.....	291,570	28,049	4,919,294.77

Secondary treatment plants cost $14,300, 972.01 and were designed to treat wastes amounting to 414,466 population equivalents and a flow of 36.55 mgd.

The oxidation pond units were designed to treat a waste equivalent to 4,800 persons with a sewage discharge of 0.49 mgd at a cost of $308,550.32.

The lagoons included in this study have been designed to serve a population equivalent of 291,570 with a waste discharge of 28.05 mgd. Cost, including intercepting structures, amounted to $8,044,830.34; cost without these structures was $4,919, 295.77.

Population Equivalent- A population equivalent (P.E.) is used to express industrial wastes and is based upon 0.167 pounds per day of 5 day, 20°C. Biochemical Oxygen Demand (B.O.D.) per person. In this manner the organic component of industrial and domestic wastes may be expressed in a common denominator.

Region VI costs are presented in Figures 4, 5, 6, and 7. Figures 4 and 5 show the total cost for each type of treatment process. These are presented on the basis of design population equivalent and flow. Design flows are expressed in 1,000 gallons per day to facilitate computation of the line of best fit. Figures 6 and 7 indicate the cost in dollars per population equivalent and cost in thousands of dollars per million gallons of wastes treated daily.

The largest and smallest plant sizes for each type of treatment facility are indicated by hash marks on the curves.

Tables Nos. 25 and 26 provide additional cost data and present a comparison of costs. The upper range in population equivalent and million gallons per day to be treated is based upon an extrapolation of the cost curves. The equation for each curve is presented in Appendix No. 1 of this paper.

The tabulations indicate that primary treatment plants for design population equivalents of 100, 1,000 and 10,000 may be population equivalent: $77.91, $40.05 and $20.58; per population equivalent for secondary treatment works, $127.30, $64.83 and $33.02; for oxidation ponds, $105.20, $53.34 and $27.04; for waste stabilization lagoons, including interceptor or outfall structures, $69.90, $34.79 and $17.32; and for waste stabilization lagoons without interceptor or outfall structures, $29.36, $18.52 and $11.69, respectively. All costs include land.

Land Costs

Land costs have been included for all treatment plant types, to obtain a complete and equitable comparison.

Land costs for 213 primary, secondary, raw sewage stabilization lagoon and oxidation pond projects were studied. Data for 10 primary facilities, 68 secondary plants, 127 raw sewage lagoons, and 8 oxidation pond installations were reviewed, and average land costs for each group were computed in $/PE. The results are presented in Table No. 27.

Included in this study is a comparison of conventional treatment plant costs includ-

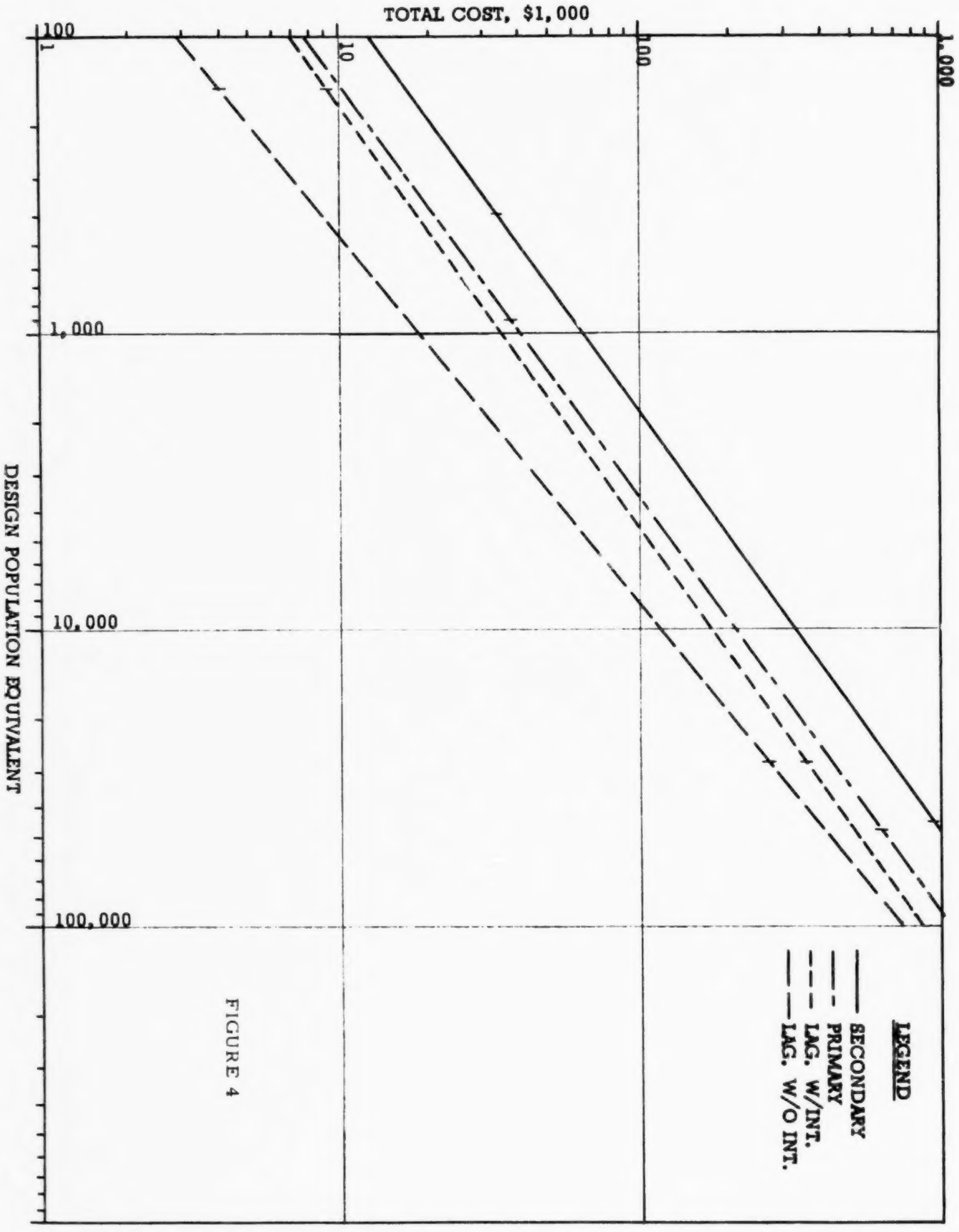

TOTAL COST, $1,000
1
10
100
1,000
DESIGN POPULATION EQUIVALENT
100
1,000
10,000
100,000
LEGEND
SECONDARY
PRIMARY
LAG. W/INT.
LAG. W/O INT.

FIGURE 4

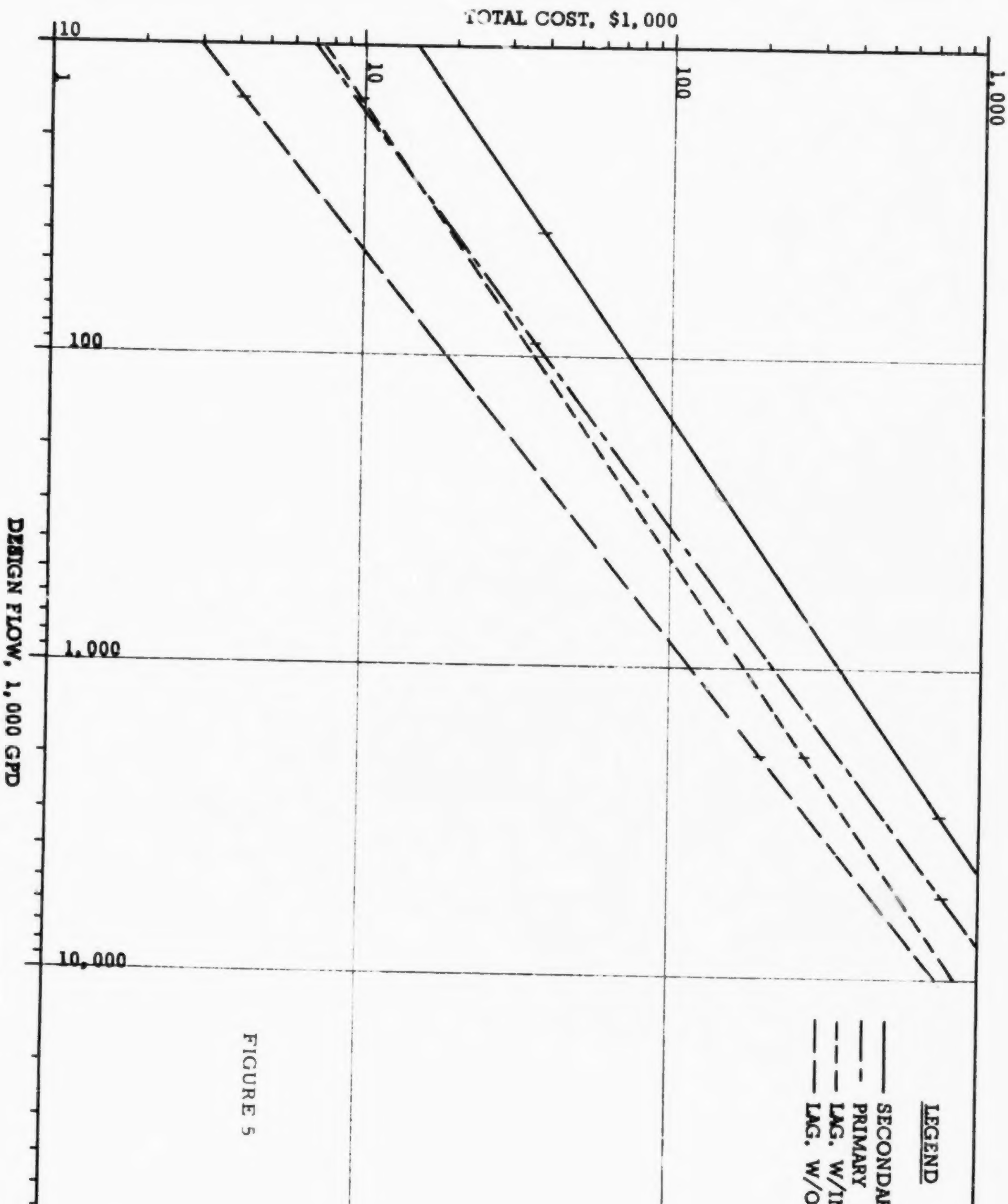

TOTAL COST, $1,000
10
100
1,000
DESIGN FLOW, 1,000 GPD
1
10
100
1,000
10,000
LEGEND
SECONDARY
PRIMARY
LAG. W/INT.
LAG. W/O INT.

FIGURE 5

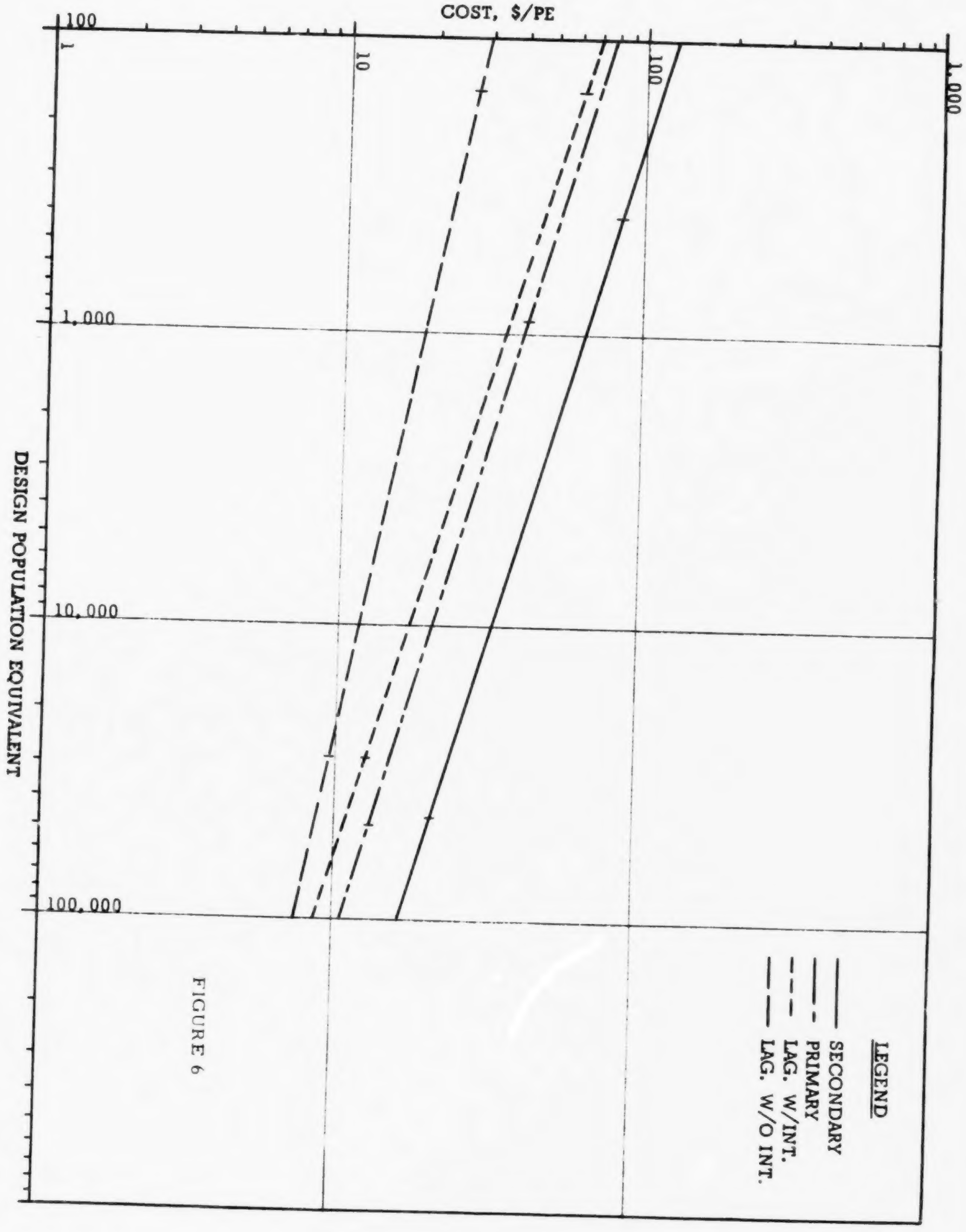

COST, $/PE
1
10
100
1,000
DESIGN POPULATION EQUIVALENT
100
1,000
10,000
100,000
LEGEND
SECONDARY
PRIMARY
LAG. W/INT.
LAG. W/O INT.

FIGURE 6

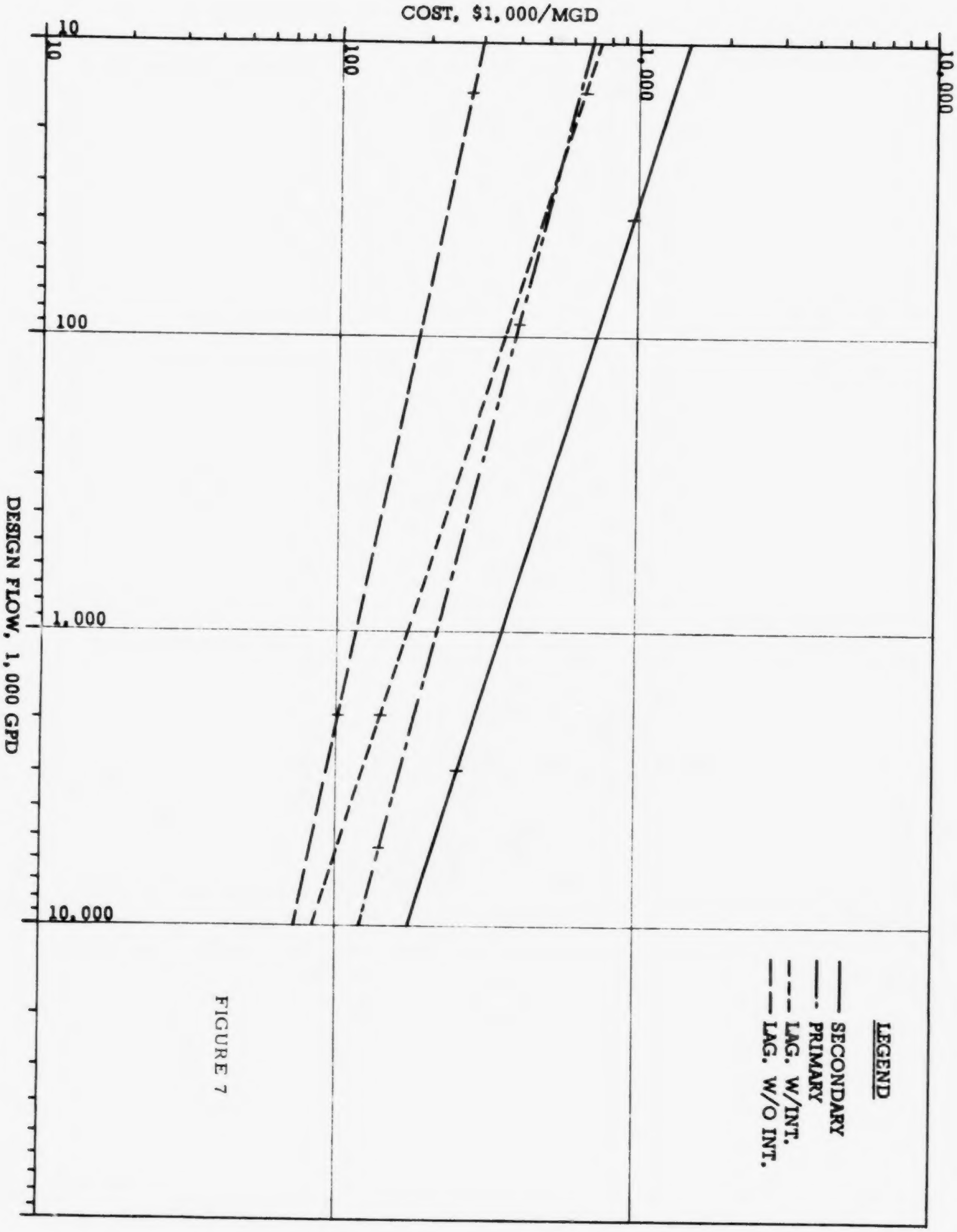

COST, $1,000/MGD
10
100
1,000
10,000
DESIGN FLOW, 1,000 GPD
10
100
1,000
10,000
LEGEND
—— SECONDARY
—·— PRIMARY
– – – LAG. W/INT.
— — LAG. W/O INT.

FIGURE 7

REGION VI

TABLE 25

Treatment Plant Costs Based Upon Design Population Equivalents

Population Equivalent	Primary	Secondary	Oxidation Ponds	Lagoons w/int.	Lagoons w/o int.
100..........	77.91	127.30	105.20	69.90	29.36
1,000........	40.05	64.83	53.34	34.79	18.52
10,000.......	20.58	33.02	27.04	17.32	11.69
100,000......	10.58	16.82	13.71	8.62	7.37

TABLE 26

Treatment Plant Costs Based Upon Design Flows

1,000 gpd	Primary	Secondary	Oxidation Ponds	Lagoons w/int.	Lagoons w/o int.
10...........	689.30	1,468.00	1,927.00	736.50	296.00
100..........	384.10	719.00	458.00	355.00	185.00
1,000........	214.00	352.20	18.90	171.90	115.70
10,000.......	119.20	172.50	25.88	83.02	72.33

TABLE 27

Land Costs for Treatment Works

Type of plant	Cost in $/PE
Primary treatment.........	1.25
Secondary treatment.......	1.20
Raw sewage lagoons........	3.10
Oxidation ponds...........	2.30

ing land with waste stabilization lagoon, construction, land, and interceptor (outfall) costs. These costs are actual construction or contract costs and land prices. Where a lift station and force main is part of the interceptor (outfall) sewer, this has been included in the cost of the lagoon treatment facility.

Another study compares cost of the conventional treatment plant including land with costs of the lagoon and land, but without the interceptor or outfall structure.

Fees for administrative, legal, engineering and technical services were not included in these costs.

DISCUSSION

One special characteristic of Region VI is the number of small communities. Cognizance must be taken of the fact that without a reasonable first cost for a treatment facility and for the operation and maintenance which follows its installation, waste treatment would be out of financial reach of a large number of these small communities.

It is apparent from the curves in Figures 4, 5, 6 and 7 that waste stabilization lagoons, with or without intercepting or outfall structures, generally cost less than primary or secondary treatment facilities. In Figures 5 and 7 the curves intersect for plants designed to treat wastes from small communities amounting to 30,000 gallons per day. However, the curve for primary plants is based upon a study of only 13 projects. If the primary curve were based upon more extensive data, the two curves might not intersect. Cost curves in Figures 4 and 6 show that the waste stabilization lagoons require a lower initial capital investment. In these figures, none of the curves intersect. The change in slope of the primary plant curve caused by the use of gauged flows instead of arbitrary flows for design purposes accounts for the fact that the curves intersect in Figures 5 and 7 and not in Figures 4 and 6.

The use of lagoons depends largely upon the feasibility of using available land. Development of waste stabilization lagoons as a treatment device may have had an initial setback because of the belief that lagoon land costs could exceed other financial benefits, such as low annual operation and maintenance costs and the initial capital investment of the structure when compared with other treatment methods.

Experience data have shown that in many cases the price of land may be fifty percent of the cost of the completed waste stabilization lagoon, yet the total cost has been equal to or less than the cost of a completed secondary treatment works. In numerous instances land costs could be double or triple the completed lagoon construction costs before equaling the conventional plant cost.

However, experience has shown that in addition to providing decided advantages of a high degree of treatment, low initial capital investment, and low operation and maintenance costs, the raw sewage lagoon possesses a flexible feature, particularly in areas which are subject to rapid population growth. In such cases it has been found that lagoons may be resited and constructed downstream and the lagoon land which may have appreciated in value can then be reclaimed for housing or industrial site development.

In addition to its use as a device for treating raw sewage, the attractive features indicated above lead to consideration of lagoons to provide a polishing of conventional, primary or secondary treatment plant effluents.

In some instances it may not be possible to procure an adequate area for the lagoon at the plant site, but may be possible to use a lagoon located at some distance from the conventional plant. When topography will not permit use of gravity piping between the conventional plant and the lagoon (oxidation pond), pumping will be necessary, and a feasibility cost study will be required.

The study showed that land costs vary widely and that variations depend largely upon the location and numerous land uses as well as intangible human factors.

The data in Tables Nos. 25 and 26 can be used to compare the approximate cost of each type of treatment facility. The study emphasizes the need for compiling more complete project data. Cost information resulting from an evaluation of these data will aid in preliminary engineering phases.

Adequate records of operation and maintenance costs have not been gathered for waste stabilization lagoons. A limited amount of data has been assembled for conventional treatment plants. On the basis of information supplied in the project engineering reports of consulting engineers, a wide range exists in the estimates of these expenditures for all types of waste treatment facilities.

These latitudes in costs are dependent upon the price in individual local areas for: Labor, fuel and power, size of plant, the amount of built-in mechanization, as well as expenditures for replacement of equipment. The simplicity of lagoon design obviates most of these costs.

Lagoon maintenance seldom requires more than two cuttings of the dike slope grass per year. The removal of scum, grease and floating algae is not generally a problem. Therefore, this operation does not require the attention associated with removal of the same material in conventional treatment plant operation. Seasonal operation of valves may be required for multiple cell installations for operation in parallel or series or where flexible depth control is exercised for optimum efficiency. Removal of emergent vegetation may be required periodically and may be minimized by providing the required liquid depth. Duties at an average conventional plant require similar, but more concentrated, effort and vigilance. The average conventional plant with a greater number of details requires more extensive attention of a skilled operator.

Estimated operation and maintenance for waste stabilization lagoons range from $0.20 to $1.00 annually per population equivalent, and from $1.00 to $4.00 per population equivalent year for conventional waste treatment plants.

Additional data are needed for lagoons serving population equivalents and design flows in the upper ranges of the graphs. When obtained, this will enable investigators to arrive at more reasonable conclusions.

SUMMARY AND CONCLUSIONS

Data presented represent a large number of sewage treatment facility cost data in Region VI. Cost data of the varying treatment processes have been analyzed and the evaluation of plants cost summarized. The results should provide a reasonable assistance to water pollution control agencies, municipalities, consulting engineers and others interested in water pollution abatement measures.

Waste stabilization lagoons cost less to construct than other types of waste treatment facilities. Land costs are slightly higher, but are offset by the lower initial capitol cost and difference in annual operating and maintenance cost. In addition, lagoons provide greater ease of relocation, possibly with financial benefits due to increased land values.

Lagoons may be used in combination with conventional treatment works to provide additional treatment capacity at a lower cost.

ACKNOWLEDGMENT

Acknowledgment is made of the participation of Thurman B. Sauls, Assistant Sanitary Engineer (R), in the preparation of this paper.

APPENDIX 1

Cost Curve Equations for
Studied Treatment Facilities in Region VI

Secondary $\$/\text{PE} = 490.70/(\text{P.E.})^{0.293}$

$\$1{,}000/\text{mgd} = 2{,}997.00/(1{,}000\ \text{gpd})^{0.310}$

$\text{Total Cost} = 490.70\ (\text{P.E.})^{0.707}$

$\text{Total Cost} = 2{,}997.00\ (1{,}000\ \text{gpd})^{0.690}$

Primary $\$/\text{PE} = 294.90/(\text{P.E.})^{0.289}$

$\$1{,}000/\text{mgd} = 1{,}237.00/(1{,}000\ \text{gpd})^{0.245}$

$\text{Total Cost} = 294.90\ (\text{P.E.})^{0.711}$

$\text{Total Cost} = 1{,}237.00\ (1{,}000\ \text{gpd})^{0.746}$

EQUATIONS

Lagoons w/interceptor $\$/\text{PE} = 282.80/(\text{P.E.})^{0.303}$

$\$1{,}000/\text{mgd} = 1{,}525.00/(1{,}000\ \text{gpd})^{0.316}$

$\text{Total Cost} = 282.80\ (\text{P.E.})^{0.697}$

$\text{Total Cost} = 1{,}525.00\ (1{,}000\ \text{gpd})^{0.684}$

Lagoons w/o interceptor $\$/\text{PE} = 73.73/(\text{P.E.})^{0.200}$

$\$1{,}000/\text{mgd} = 473.40/(1{,}000\ \text{gpd})^{0.204}$

$\text{Total Cost} = 73.73\ (\text{P.E.})^{0.800}$

$\text{Total Cost} = 473.40\ (1{,}000\ \text{gpd})^{0.0796}$

Oxidation Ponds $\$/\text{PE} = 409.30/(\text{P.E.})^{0.295}$

$\$1{,}000/\text{mgd} = 8{,}108.00/(1{,}000\ \text{gpd})^{0.624}$

$\text{Total Cost} = 409.30\ (\text{P. E.})^{0.705}$

$\text{Total Cost} = 8{,}108.00\ (1{,}000\ \text{gpd})^{0.376}$

Bibliography

Fair, Gordon Maskew, and Geyer, John Charles

Water Supply and Waste Water Disposal. John Wiley and Sons, Inc., New York, (1956)

Howells, D. H., and Dubois, D. P.

Design Practices and Costs for Small Secondary Sewage Treatment Plants in the Upper Midwest.

Sewage and Industrial Wastes, Vol. 30, No. 11, November, 1958.

SOME OBSERVATIONS ON THE GROWTH, APPLICATION, AND OPERATION OF RAW SEWAGE STABILIZATION PONDS

W. W. Towne and W. B. Horning*

INTRODUCTION

To avoid unnecessary repetition of material already covered we will present some general comments relating to the growth, application, and operation of this method of sewage treatment. Therefore, we will briefly discuss: (1) the factors influencing the growth and use of raw sewage stabilization ponds in the United States; (2) the conditions affecting the applicability of this type of sewage treatment; and (3) some of the operating problems that have come to our attention both within the United States and in foreign countries. In closing we would like to present some general conclusions that have developed as a result of our association with the problem over the past several years and to point out some of the questions yet to be answered.

It is realized that the stabilization ponds, oxidation ponds, lagoons, or whatever you prefer to call them, have been in use in this country for many years. In fact, they are probably one of the oldest man-made sewage treatment devices. Previous to 1948, however, when the first ponds were constructed at Mattock, North Dakota, the process had been looked upon as an adjunct or supplementary treatment process rather than a complete method of sewage treatment. It is only within the past few years that ponds have been used extensively in this capacity. This early phase of the development in the Dakotas has been well documented here by Mr. Svore. Without question many communities are now enjoying a higher standard of living and health protection because of the foresight of these early investigators. This early apprehension was extensive and many could not visualize the application of stabilization ponds as a complete method of sewage treatment even in those areas where the facilities had been used as secondary or tertiary treatment devices and where they had demonstrated their ability to stabilize organic matter.

EARLY GROWTH

During the early 1950's then, the process entered a trial period and those that had observed the results became more and more convinced that this system of sewage treatment definitely did have an area of application. It was also recognized that additional scientific information was essential concerning the factors involved in the stabilization of organic matter, if rational design criteria were to be developed. Further evidence of this spreading interest was the resolution adopted by the State and Territorial Health Officers Conference in 1954 asking the Public Health Service to investigate this method of treating raw sewage and to determine the various design factors, their effectiveness and details of operation. The Regional Office, here at Kansas City, had also been following early developments in the Missouri Basin and in 1954 representatives of that office, the Robert A. Taft Sanitary Engineering Center, and the States of North and South Dakota developed plans for a cooperative study to obtain seasonal operating data at five different installations in the two States.

Concurrent with this work other investigators were conducting research relating to the performance of oxidation ponds and the factors affecting the algal-bacterial relationships involved in the stabilization processes. The University of California has long been the focal point for this type of research; Gotaas, Ludwig, Oswald, and associates have all made outstanding contributions to a better understanding of the phenomena involved. Herman and Gloyna, at the University of Texas, also were actively engaged in research on the subject, as were many others.

---

*Chief, Field Operations Section, and Biologist, Field Operations Section, respectively, Technical Services Branch, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

While the Public Health Service fully recognized the importance of this basic research and, in fact, contributed to its support through research grants, the need to evaluate the field application of the research findings in many sections of the country was recognized. The Public Health Service was also interested in developing an adequate low-cost method of sewage treatment requiring a minimum of technical supervision and maintenance. To this end the major effort of the Public Health Service has been directed to field observations and studies.

While these early studies did not develop mathematical design formula they did point out general design factors that required consideration and demonstrated that properly designed and operated stabilization ponds would provide a degree of purification comparable to that obtained by conventional complete treatment processes and that the effluent might be discharged in a similar manner. At the same time it was fully recognized that like any other sewage treatment process, stabilization ponds had advantages and disadvantages and they should not be considered as a panacea for all sewage treatment needs, but that their use deserved to be considered in the economic and engineering evaluation of waste treatment methods. This type of field evaluation was no doubt instrumental in obtaining general acceptance by many regulatory agencies.

Another important benefit of these field evaluations was related to the Construction Grants Program of the Federal Water Pollution Control Act which got under way late in 1956. Because our observations and investigations clearly supported the efficacy of this type of treatment, the Service felt justified in approving this method of sewage treatment as being eligible for construction grants. During the first two years of the Construction Grants Program 254 projects in 29 states in which stabilization ponds was a method of treatment were approved for Construction Grants. Fifteen months later, namely as of March 31, 1960, Grant offers had been made on 443 projects in 32 states. Some of these were for stabilization ponds operating either as secondary or tertiary treatment units. However, as of May 31 of this year 418 raw sewage stabilization pond projects have been approved for construction in 27 states. In addition to these Federal aid projects, many projects have been constructed without such aid and this type of treatment is now being used in at least 39 states either for complete or partial treatment of domestic sewage. This process is also being used by an increasing number of industries.

Judged by our experience these facilities have functioned with a minimum of difficulty and complaint other than the usual problems often associated with placing any new sewage treatment plant in operation. Thus, it would appear that the use of stabilization ponds for treating raw municipal sewage is now beyond the trial period and we are now approaching the time when our efforts should probably be directed at refining design criteria so that their application can be extended into other areas and their cost may be further reduced.

APPLICATION OF THE PROCESS

As previously stated, this process is not a panacea for all sewage treatment problems but certain features make it especially applicable under a wide variety of conditions. All of us recognize that because of the relatively large land area required, the greatest application will no doubt be small communities, where land is readily available but where the per capita costs for conventional treatment plants are high and the revenues correspondingly low. Without question this practical minimum cost method of sewage treatment has made it possible for many communities to afford a community water-carried sewerage system with its related conveniences and benefits that would otherwise have been impossible.

However, the facility is not limited in its application to small communities alone. It has been demonstrated to have a very real place in meeting the needs of our expanding metropolitan areas. The problems associated with the sanitary aspects of suburban housing are known to all of us. We all realize the limitation of individual waste disposal systems and the desirability of community systems for metropolitan areas. In the initial developments stages, however, the high capital investment and the initial limited tax base often make it impossible to construct both the necessary system of sewers and conventional treatment works. This frequently results in the construction of individual disposal systems in areas not suitable for their use which at the best may prove to be only a costly stop-gap solution to the problem. These difficulties can be materially reduced if sewage treatment processes with low first cost, minimum operating costs, and capacity for easy expansion, can be provided. In many instances, such treatment devices may be needed only as an interim facility until the time that several developments can merge into a combined collection and treatment works. In such cases, salvage value of the initial sewage treatment installation is also important.

It is in this field that the stabilization pond has found real application. The reasons are quite apparent. First, in the initial stages of the development a greater or lesser amount of land is available and part of this can often be set aside for a stabilization pond including a buffer strip surrounding it. Secondly, the system of ponds necessary to serve the ultimate development can often be built in stages as the population load builds up. Thirdly, the pond area can be very economically reclaimed for future housing developments if and when subdivision can join a combined sewer district, thereby realizing an almost 100 percent salvage value. In fact, the reclaimed area may have a considerably greater value than the raw land did when the development was started. A fourth and very important advantage is that the cost of sewer construction is much less on raw land than when the development is complete and individual treatment plants have to be replaced by a community system. Many areas have used the stabilization ponds most effectively for this use, the most extensive of which has been right here in the Kansas City area.

Other areas that have taken advantage of this method are the Metropolitan Sanitary District of Greater Chicago, Pittsburgh, Denver, Seattle, and several areas in Mississippi. There may be others. The Chicago situation offers what appears to be an ideal situation. Within the past few years the Sanitary District has taken in a considerable area north and west of the old District boundaries for which it is responsible for collecting and treating the waste. It will take considerable time to provide intercepting sewers to serve all this area and the District has effectively utilized stabilization ponds to serve these communities and newly developed housing areas until such a time as the sewer collection system is extended.

Other areas in which stabilization ponds have been effectively used include national parks, Indian reservations, tourist courts, boarding schools, and isolated military installations. Many of our national parks operate on a seasonal basis and have an extremely fluctuating load. Stabilization ponds have many advantages for such conditions. First, the period of operation during the summer season is that period when the maximum biological activity exists and when the maximum loading can be applied. Secondly, the stabilization pond requires no extensive breakin period such as an activated sludge plant or trickling filter. Stabilization ponds have no discharge until they have filled to an operating level at which time the processes of purification are fully established. Thirdly, the simplicity of operation has many advantages where technical supervision is usually limited.

The Bureau of Indian Affairs has used this method of treatment quite extensively on many reservations and boarding schools. Here again the simplicity of operation and maintenance are of particular importance. Probably one of the most interesting applications of this method of treatment exists in Alaska where a stabilization pond was constructed to serve a school at Fort Yukon some eight miles north of the Arctic Circle. This is in the permafrost area where any conventional type of water-carried sewerage presents many costly and difficult operation and maintenance problems. In an effort to develop improved methods of sanitary sewage disposal the Arctic Health Research Center of the Public Health Service, at Anchorage, working with the Bureau of Indian Affairs and the Alaskan Health Department developed a design for a stabilization pond to serve the public school at Fort Yukon. This facility has operated satisfactorily through two winters and is providing a simple and economical method of waste treatment and disposal for this area. This likewise is a seasonal operation but in this case the off season is summer. Anderegg and his associates have reported on this and other installations in Alaska. (1)

As the use of stabilization ponds has expanded in the municipal field many industries have likewise shown an interest in the application of this type of treatment for various types of industrial wastes. The use of ponds or lagoons as an adjunct to industrial waste treatment and disposal is not new. In fact, such use can be traced back for several decades and it is likely that they existed prior to the time that their use was recorded in the literature. Usually, however, stabilization of the waste was not the primary objective. They were usually used as seepage pits, settling basins, or for holding industrial wastes until greater dilution was available in the receiving streams.

The lagooning of vegetable canning wastes has been practiced for many years but the organic loadings were invariably of such magnitude that anaerobic decomposition always resulted, often accompanied by offensive odors requiring the application of sodium nitrate for odor control. More recently, however, several industries are installing stabilization ponds as a complete treatment unit. A preliminary review of this application summarized some 40 or 50 installations serving at least 10 different types of industry. (2) These installations varied widely in loadings and types of waste being treated, as well as in design features such as depth, size of installation, and methods of operation. As would be expected organic wastes that have been successfully treated by conventional biological processes have also been amenable to treatment in stabilization ponds. Similarily, those wastes that require addition of certain nutrients to support biological life in conventional treatment may also require the addition of nutrients to provide effective pond treatment.

In general, it may be stated that there is less uniformity in the design criteria being applied to the design of industrial waste installations just as there is less uniformity in the character of the wastes.

The many applications of this treatment have not been limited to the United States. Concurrent with the publication of research results and reports on the successful use of the aerobic type of stabilization process in this country, many inquiries were received by the Public Health Service from numerous foreign countries. A large number of foreign visitors pass through the Sanitary Engineering Center annually. Probably no other subject is of more universal interest to these people, and ponds have been constructed in many foreign countries following the general design criteria developed in this country. Through an exchange of correspondence and reports concerning operating data, experiences, and problems, there has been much mutual benefit. The Public Health Service is deeply indebted for this continued interest and assistance.

OBSERVATIONS ON DESIGN AND OPERATION

Probably one of the most common questions in the minds of many of our visitors is how do design criteria which may be suitable for cold climates apply to their country. If there has been any one thing that may have contributed to the lack of understanding and confusion concerning design criteria, it has been this failure to recognize two extremes in climatic conditions that may require entirely different approaches in design, i.e., ice cover vs. open water. Naturally, in those climatic regions where long periods of ice cover prevail it is impossible to maintain aerobic conditions even with the lowest possible loading. Consequently, factors governing the maintenance of an aerobic environment under open water conditions no longer apply. During such periods anaerobiasis is a certainty and the pond temperatures are only slightly above freezing. This results in a very much slowed up biological activity with the resultant accumulation of sludge deposits which are not dispersed because of almost complete quiescence. These solids remain in a refrigerated condition until spring when increased temperatures speed up biological action, and the winter's accumulation of fresh sludge begins to digest anaerobically at such a rate that so-called "acid digestion" prevails, with a lowering of pH and the potential production of hydrogen sulfide gases. Many of us who have lived in these colder climates remember similar periods of spring time complaints with Imhoff tanks.

It is fully recognized that during the summer months loadings considerably higher than those commonly advocated here in the Plains States can easily be handled. However, unless there is adequate isolation to minimize the effect of odors that may prevail during the spring break-up period it has been the policy to reduce loadings so that the time required for transition from anaerobic to aerobic conditions will be minimized. In those climates where ice coverage does not prevail, it has been demonstrated that much higher loadings than those common in our northern States are practical. This has been borne out by actual experience both in this country and abroad. The Public Health Service experimental ponds at both Fayette, Missouri and Lebanon, Ohio, have operated with a minimum of odor at loadings approaching 100 lbs. of 5-day BOD per acre per day, even though there have been moderate periods of ice cover and resulting anaerobiasis.

Personal communications from two foreign sources may also be of interest. Mr. H. D. Hodgson, Government Health Inspector in South Rhodesia, South Africa, reports that loadings of slightly over 800 population per acre per day had been handled satisfactorily. Mr. Harold A. Taylor, Chief Health Inspector, Ministry of Local Government Health Housing, Nairobi, in commenting upon the operation of pilot sewage lagoons in Kenya Colony, East Africa, states that aerobic conditions were maintained with loadings in slightly excess of 200 lbs. of 5-day BOD per acre per day. However, when this load increased to approximately 300 lbs. per acre per day, the pond lost its green color and anaerobic conditions accompanied with typical septic odors developed. In these warmer climates it would also seem reasonable to expect that anaerobic action would be less likely to produce objectionable odors. Under such conditions once alkaline digestion is established the resulting gases of decomposition should be essentially the same as those from normal functioning, unheated, sludge digester and should be no more objectionable. Therefore, in such areas, it may not be necessary to design to satisfy the accumulative effects resulting from a sludge build-up under long periods of ice coverage.

While the studies in this country have been primarily related to the phenomena taking place in aerobic environments the above discussion logically leads to the question of what would happen should we utilize anaerobic lagoons. All of us have read with much interest the pioneering work that has been done in this field by Mr. Parker and his associates in Melbourne, Australia and we are indeed fortunate in having him present here at this conference. He should know, however, that the results of his work have preceded him to this country and we already have in operation at least two ponds employing the anaerobic-aerobic principle following his general design criteria.

These two installations are located at Long Beach and Redmond, Washington. The first installation was studied by the Public Health Service and was reported on at the most recent Industrial Wastes Conference at Purdue in May of this year. (3) This resort community on the Pacific Ocean near the mouth of the Columbia River has high summer and low winter populations resulting in extreme variations in loading. The observed loadings ranged from 185-450 lbs. of 5-day BOD per acre per day on the primary ponds, with reduction ranging from 40-70 percent, the majority approximating 60 percent. The aerobic pond loadings varied from 13-40 lbs. of 5-day BOD per acre per day resulting in reductions varying from 50-85 percent. The over-all BOD removal at this installation ranges from 74-96 percent. It may be of interest to report that during the study period algal growths were frequently evident at the surface of the anaerobic ponds while anaerobic digestion of sewage solids was taking place at the bottom. In general, the operation of this facility has been extremely satisfactory. Some septic sewage odors were noticed during the summer months in the late evening hours but the operator reports that these were quite effectively controlled by recirculating from the aerobic pond to the anaerobic ponds for a period of approximately two hours during the afternoons when the dissolved oxygen content in the former ponds was at a maximum.

The other installation at Redmond, Washington serves a residential development adjacent to Seattle. The Washington State Health Department and the State Water Pollution Control Commission approved this as an experimental treatment plant to be abandoned when interceptor sewers were provided by the municipality of Metropolitan Seattle. A study of this installation was conducted during the period October 1958 to September 1959 by Mr. Walter L. Berschauer a graduate student at the University of Washington, now with the Washington Health Department. The authors are deeply indebted to Mr. Berschauer for a copy of his thesis "Research and Investigation on a Multiple Cell Sewage Stabilization Pond" and his permission to use some of the data.

A series of analyses extending from March 19 to June 25, 1959 gave the following results:

The anaerobic pond was loaded at a rate of 463 lbs. of 5-day BOD per acre per day while the entire aerobic section was loaded at a 20-lb. rate. However, since the aerobic section consisted of three ponds in series the load on the first pond was approximately 75 lbs. per acre per day. The two remaining ponds resulted in relatively little additional BOD removal but did serve to reduce the number of algae in the final effluent. The removals average 61 percent for the anaerobic pond with an over-all reduction of 91 percent. Berschauer reports that during winter operation little or no odors were detected in the anaerobic section. Odors were noticeable in the early spring from this section, at which time rapid gas production was apparent and this carried solids to the surface. Such odors as appeared on the aerobic ponds were of a fishy nature and were attributed primarily to algae.

As a result of his studies Berschauer concluded that BOD loadings as high as 78 lbs. per acre per day could be applied on the aerobic ponds and loadings in excess of 555 lbs. per acre per day could be applied to the anaerobic ponds without difficulty.

CONCLUSIONS

In concluding this rather rambling discussion of where we started, where we are, and where are we going, I think we can point out some well substantiated accomplishments.

1. Research and field studies carried out in this country during the past ten or so years have definitely proved the efficacy of raw sewage stabilization ponds as a practical minimum-cost method of sewage treatment having wide application throughout the world.

2. Properly designed and operated stabilization ponds may be expected to provide a degree of purification comparable to that obtained by conventional complete treatment processes and the effluent may be discharged in a similar manner. Like any other sewage treatment device stabilization ponds have both advantages and disadvantages. They should not be looked upon as a panacea for all sewage treatment needs but may be considered in the economic and engineering evaluation of waste treatment methods.

3. Although stabilization ponds appear to be simple in their design and operation, it is essential that they be designed by people having a thorough knowledge of the factors contributing to their success and/or failure. The design criteria may vary radically between different climatic and geographic areas and for these reasons the designing engineer should not attempt to blindly apply such criteria without considering the local factors involved.

4. On the basis of operating experience in this country and abroad, organic loadings of at least 100 lbs. of 5-day BOD per acre per day are no doubt feasible for ice-free climates or where potential odors at ice break up are not a controlling factor.

5. The factors to be considered in location and site selection for these facilities are essentially the same as for other more conventional types of sewage treatment plants.

6. While there is no epidemiological evidence indicating that stabilization ponds constitute a serious public health hazard, the potential for the propagation of insects and other possible disease vectors is no doubt

greater in ponds than at conventional treatment works and requires consideration by the designer.

Although our knowledge of this method of waste treatment has increased greatly during the last 10 or 15 years this has also made us cognizant of the need for even more knowledge on the subject. The following comments point out several areas in which our knowledge is lacking.

1. Naturally, we need much more fundamental information on the whys and wherefores of algal-bacterial relationships and the factors affecting them. One prominent researcher in the field recently told me that he felt much more confident of his understanding of the basic factors after one or two years of working with the problem than he does now after several years of effort. Without doubt, much, much more basic research is needed together with the related field studies and observations necessary to fully evaluate the applicability of these scientific findings. On the other hand, I seriously question that we will ever be able to develop design formula that will adequately consider the variability of all factors affecting the functioning of the processes. At least we cannot wait for that time to experiment with new ideas and apply the available knowledge toward providing better and lower cost sewage treatment.
2. The viability of pathogens and virus and possible bactericidal action of algae require additional study.
3. More knowledge concerning effective insect control measures is highly desirable. Although we have experienced very little difficulty from this problem in this country, we have received reports where it has become a serious problem elsewhere. Also, if these facilities are going to have world wide application we need to give consideration to possible control methods for other types of disease vectors. One of these that comes readily to mind is the possible significance of stabilization ponds as a link in the chain of transmission of schistosomiasis where that disease is prevalent.
4. Greater effort should be devoted to the evaluation of this method of waste treatment for wider application in the industrial field.
5. The application of anaerobic-aerobic processes deserves consideration. This would appear to have application in warmer climates where cyclic sludge problems are less likely.
6. Consideration should be given to incorporating various adjuncts or additional types of equipment in the design of these facilities in order to improve their efficiency. For instance, the reported beneficial effects of recirculation during limited critical periods warrants further evaluation. We should not lose sight of the fact, however, that the addition of mechanical equipment with its attendant demands for maintenance tends to nullify one of the principal advantages of this method of treatment, namely, simplicity. On the other hand, the area requirements and short-time critical seasonal problems may well warrant the inclusion of mechanical devices purely from an economical standpoint.

These are just a few of the areas in which I believe we need to direct our future efforts. I am sure that before this symposium is finished, many other areas of investigation will become apparent.

In closing I would like to say that I think that it is very appropriate that this symposium is taking place here in the general area where raw sewage stabilization ponds got their start and I wish to commend the Missouri Basin Engineering Health Council for initiating this meeting.

REFERENCES

1. Anderegg, J. A., Walters, C. F., Hilliard, D., and Meyers, H. F., " 'Eskimo' Algae Make Lagoons Work at the Arctic Circle." Wastes Engineering, 31, No. 6, June 1960.
2. Towne, W. W., and Pahren, H. R., "Use of Stabilization Ponds in Treating Sewage and Industrial Wastes." Proc. 8th Southern Municipal and Industrial Wastes Conference, Chapel Hill, North Carolina, April 1959.
3. Wilson, J. N., McDermott, J. H., and Livingston, A., III., "Performance of a Sewage Stabilization Pond in a Maritime Climate: 1957-1958." Proc. 15th Purdue Industrial Wastes Conference, May 1960. (In Press)

WASTE STABILIZATION LAGOONS
DESIGN, CONSTRUCTION, AND OPERATION PRACTICES
AMONG MISSOURI BASIN STATES

Glen J. Hopkins*

Before 1950, use of lagoons as sole and permanent sewage treatment facilities generally were discouraged. About 1952, great upsurge of interest in their use at many localities throughout the country emphasized the desirability of documenting the design, construction, and operating practices generally used. At its 1958 meeting at Deadwood, South Dakota, the Missouri Basin Engineering Health Council, in recognition of this need, appointed a Committee to accomplish this objective. The Committee report, approved by the Basin Council on January 21, 1960, serves as the basis of my presentation today, and copies of that report are available today, for anyone interested.

The Committee soon realized that waste stabilization lagoons have been adapted for successful use under highly varying conditions. Like other methods of sewage treatment, they can be designed to provide intermediate, secondary, or higher levels of removal. Variations in water quality, rain fall, evaporation, water use per capita, soil conditions, nature of receiving watercourses, dilution water available, uses of the receiving waters, and similar factors permit design to vary widely.

The many installations demonstrating satisfactory performance with highly divergent design criteria, impressed the Committee that it was not desirable to outline firm design criteria. Its members elected to outline range of design practices satisfactorily employed in the Basin, leaving each individual State wide latitude as to specific practices to be recommended for that State.

The Committee report was based on the best information now available, heavily influenced by experience in those States having a large number of installations, and the premise that waste stabilization lagoons are a proven and demonstrated method of satisfactory waste disposal to be considered, along with other methods of treatment, in the engineering and economic analyses leading to final selection of a sewage treatment facility.

The terms "recommended" and "should" are use to denote widely used practices, and do not imply a mandatory requirement for any specific State or installation.

At its 1956 meeting at Helena, Montana, the Missouri Basin States adopted the terminology of "waste stabilization lagoons". Similar action was taken by the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers at the March 1959 meeting at Chicago, Illinois. In this discussion, the terms "waste stabilization lagoons", "stabilization lagoons" and "lagoons" are used interchangeably. The term "ponds" is still used by some of the Basin States.

PRELIMINARY ENGINEERING REPORT

As for other sewage treatment works, a preliminary engineering report on the proposed facility should be prepared and submitted to the appropriate State agency for review prior to development of final plans and specifications. This report should indicate the location and topography of the proposed site, volume and characteristics of sewage flow, industrial wastes, size and shape of units, surface and subsurface soil conditions, nature of receiving watercourses, downstream water uses, dilution water available, and geographical location with respect to residences, commercial development, water supplies and other topographic features.

Preliminary reports should be reviewed and evaluated on an individual basis, with local conditions receiving appropriate consideration.

---

*U. S. Public Health Service Region VI, Kansas City, Missouri.

LOCATION

Stabilization lagoons, like other sewage treatment facilities, should be located as far away from existing and future residential and commercial developments as is reasonably practicable and economically feasible. Like other sewage treatment facilities, location of a waste stabilization lagoon depends upon many factors and each installation merits individual consideration. If not unduly influenced by cost, consideration should be given to the probable course of possible expansion and the direction of prevailing winds. Other factors permitting, preference should be given sites that permit unobstructed wind action on water surface.

Early installations had the benefit of considerable separation from residences, and the impression developed that substantially greater remoteness is required for lagoons than for other sewage treatment devices. Experience has demonstrated that lagoons usually can be located as close to habitation and other developments as can other sewage treatment processes. Generally, it is recommended that isolation requirements for lagoons be identical with and determined by the same factors that are associated with other sewage treatment plants. As with other plants, provision for probable future expansion, including land availability, may well be considered.

While no evidence of underground pollution affecting water supplies has been attributed to existing installations, the significance of pollution of underground waters is so great that this aspect of location merits very serious consideration. Except for fissured rock or coarse gravel formations, travel of bacteriological pollution through significant horizontal soil distances is not considered probable. Chemical pollution, including detergents, may travel much further than bacteriological pollution in normal soil formations.

AREA AND LOADING

Early stabilization lagoons in North Dakota were located in areas of inexpensive, relatively level land, and were basically designed for one acre of water surface per 100 population, or population equivalents, of organic wastes expressed in terms of 5-day 20° C B.O.D. This basis of design was predominantly one of economics and experience, since cost was well within the financial capabilities of North Dakota communities and the installations performed quite satisfactorily. Later experience in North Dakota revealed that substantially heavier loadings, arranged primarily to insure water level maintenance, did not mitigate against successful performance. Similar experiences have been observed in Missouri, Kansas, Nebraska and Wyoming.

Five day 20° C B.O.D still is used as one factor of design in most States of the Missouri Basin. Total first stage B.O.D., has on occasion been used, particularly where significant industrial wastes are involved.

Loadings, and subsequently the lagoon area, are influenced by many factors, including, but not necessarily limited to: water use per capita, evaporation, rainfall, seepage, the degree of treatment desired, growth prospects, and the basic plan of operating the facility. Optimum loading and area should reflect appropriate consideration to all pertinent factors.

In cold climates, where substantial ice cover may be expected for an extended period, it may be desirable to operate the facility to retain all wintertime flows. In other climates, lagoons may be operated on a "flow-through" principle, with continuous overflow. In some instances, essentially complete retention may serve as a basis of design rather than B.O.D. loadings.

"Flow-through" lagoons receiving raw sewage normally employ a minimum of 60 days retention, with 90 to 120 days frequently specified. A high degree of coliform removal is assured even with 30 day retention. Installations receiving partially treated sewage may provide lesser retention, usually in relation to the degree of reduction accomplished by prior treatment.

Lagoon loadings of from 10 to 34 pounds of 5-day 20° C B.O.D. per acre per day have demonstrated satisfactory service throughout wide areas of the Missouri Basin. The lower range permits longer retention and greater flexibility for handling future increases in waste loadings from population growth or industrial increases. However, the lower loading generally results in a lesser volume of sewage per unit of area, and enhances the possibility of operational difficulties brought on by inability to maintain satisfactory liquid depth, particularly in areas of low per capita water use, low rainfall, high evaporation, or significant seepage. While primary consideration is given to organic loading, in many instances the area finally decided upon is based upon both the organic loading and the hydraulic loading.

Lagoons have clearly demonstrated ability to handle satisfactorily substantially higher loading during summer periods, making them particularly appropriate for resort areas and similar instances where heavy summer population is anticipated.

B.O.D. loadings up to 68 pounds of 5-day B.O.D. per acre have been employed in Missouri, particularly in sub-divisions where land costs are high and the lagoon is planned as an interim installation, to be replaced in reasonable time by trunk sewers leading to a more permanent installation. These higher loadings are permitted only for installations viewed as "temporary", and must include provision for dosage of sodium nitrate as needed.

For lagoon units operated in series, design should recognize that the entire organic load will be applied to the primary unit.

Lagoons should be of such shape that there are no narrow or elongated portions. Round, square, or rectangular units with length not exceeding three times the width, are considered most desirable. Dikes should be rounded at corners to minimize accumulation of floating materials.

MULTIPLE UNIT INSTALLATIONS

Many Missouri Basin installations employ multiple units, some operating in parallel, others in series. Series operation is beneficial where a high level of B.O.D. or coliform removal is important. The effluent from secondary units in series operation has much lower algae concentrations, with resultant decreases in color and turbidity. However, some multiple unit in-series operating installations have been designed to provide virtually complete retention of wastes.

Many installations provide flexibility so that units may be operated either in series or in parallel. Except for small installations, this has considerable advantage. This may also be important in areas of low water usage, high evaporation, or considerable seepage. For small installations (6 to 8 acres) a single unit seems conducive to better circulation, but reasons other than circulation make two units preferable even for small installations.

The additional cost of equipping units for both series and parallel operation is usually quite nominal. In some instances, actual savings can be demonstrated because of the lesser volume of earth work possible through better adaptation of two or more smaller units to over-all topography. The flexibility may have substantial advantage, particularly as volume and loading are increased through population growth or other causes. Except for small installations (6 to 8 acres or less) it is recommended that units be designed to permit both series and parallel operation as desired.

For larger communities, two or more units have advantage over a single unit. Wave action is more intense on larger bodies of water, and prevailing topography often permits lesser construction costs through multiple units. While circulation is influenced by area, there appears to be little advantage in this respect to installations in excess of 40 acres.

SURFACE RUNOFF

Lagoons should not receive significant amounts of surface runoff. If necessary, provision should be made for diverting surface water around the ponds. For new installations, and for installations where maintenance of satisfactory water depth may be a problem, the diversion structure may permit entrance of the surface water into the lagoon when desired, yet preclude it at all other times. Silt that would be carried into the installation by runoff must be considered.

DIKES

Dikes should be so constructed as to prevent excessive seepage through the dikes or between the embankment and the natural ground. Compaction afforded by the use of conventional construction equipment is usually adequate. Prior to starting the embankment, vegetation should be removed, and the area upon which the embankment is to be placed should be scarified. While experience demonstrates that it is generally unnecessary to key the dikes into impervious subsoil, this precaution may be advisable for sandy top soils or for dikes reposing on shale or similar formations.

The dikes should be of sufficient width to accommodate mowing machines and other maintenance equipment. A width of 8 feet is generally considered adequate, and lesser width may be approved for small installations.

Dike slopes may be influenced by the nature of the soil and the size of the installation. For outer slopes, 3 horizontal and 1 vertical is conducive to satisfactory maintenance, although economical use of excavation material may warrant flatter slopes. Inner slopes are generally designed from 3 or 4 horizontal to 1 vertical, although slopes exceeding 5 to 1 are sometimes specified for larger installations, and slopes steeper than 3 to 1 may be warranted for small installations. Flat inner slopes have the distinct disadvantage of added shallow areas conducive to emergent vegetation. Wave action is more severe for larger installations, warranting consideration of flatter inner slopes. However, observation reveals that a given installation will develop a particular slope at the water line rather independent of the slope originally provided, the constructed slope being adjusted by wave action to give a "dished" effect near the water line.

The freeboard to be specified is to some extent influenced by the size and shape of the installation, as wave action is more pronounced on larger bodies of water. Freeboard should be sufficient to facilitate necessary maintenance operations without accident hazard. Three feet above maximum liquid level is usually specified as minimum freeboard. However, 2 feet is considered adequate by some States, particularly for installations of 6 acres or less not exposed to severe winds.

LIQUID DEPTH

Optimum liquid depth is influenced to some extent by lagoon area. Relation of depth to size should be such as to facilitate circulation within the body of water, and larger installations may allow greater liquid depth than would be considered for a smaller facility. The basic plan of operation may also influence depth. Lesser depths are conducive to emergent vegetation and enhanced mosquito breeding. Experience in the Kansas City area has demonstrated 2 to 3 feet as the most desirable operating depth during the prolonged periods of cool, cloudy weather, occasionally encountered in early spring or late fall. These installations serve subdivisions, are heavily loaded, and are less than 10 acres in area. Experience has demonstrated however, that greater depths are desirable during the summer to discourage emergent vegetation.

Experience has conclusively demonstrated the advantage of facilities which permit operation at selected depths up to 5 feet, and provision for additional depth may be desirable for large installations. Facilities for adjusting water levels can be provided at little increase in cost, and permit operational flexibility of considerable advantage. For example, where winter retention is visualized, the operating level can be lowered as desired before ice formation and gradually increased by the retention of winter sewage flow. In the spring, the level can then be lowered to any desired depth at the time surface runoff and dilution water are generally at a maximum. Shallow operation can be maintained during the spring, increasing the depth as necessary to discourage emergent vegetation. In early fall, the levels can be lowered before cloudy periods are encountered and again be ready for retention of winter sewage. In areas of high evaporation, as Western Kansas, a full lagoon in late spring may well be an operating objective.

Facilities to permit operation at selected depths are desirable for any installation, and can be provided at very little increase in cost. For lagoons of considerable size, provision for periodic operation at depth greater than 5 feet may be advantageous.

LAGOON BOTTOM

The lagoon bottom should be made as level as possible with conventional dirt moving equipment and operations, and the finished elevation should not vary more than plus or minus 6 inches from the average elevation of the bottom.

The lagoon area should be cleared of excessive vegetation and debris. This material should not be included in the waterside two-thirds of the embankment, but may be used if judiciously placed in the outer third of the embankment. Rock or other porous material may also be placed in the outer one-third of the embankment, but should be covered with earth to facilitate maintenance.

The bottom should be well compacted and relatively tight to avoid excessive seepage. Removal of porous top soil and compaction of subsoil improve the water holding characteristics of the bottom, and adequate compaction may be as important in this regard as soil characteristics. Proper compaction can usually be accomplished through judicious use of conventional earth moving equipment, although additional treatment, as sheep-foot rolling, may be justified.

The ability to maintain a satisfactory water level in the lagoon is one of the most important aspect of design; one for which the consulting engineer must assume responsibility. Where excessive percolation is a problem, increased hydraulic loading or partial sealing may merit consideration. Porous areas, as gravel pockets, should receive particular attention. Removal of gravel or sandy pockets and replacement with well compacted clay or other suitable material may be indicated. Limiting values of acceptable percolation may be merited in some areas, as a measure against which sealing of porous bottoms will be required.

Influent pipes discharging vertically upward have been successfully used, but appear to demonstrate no advantage. Some States discourage a vertical discharge because of possible accumulation of grit in the lime. For horizontal discharge, a suitable concrete splash plate should be constructed around the point of discharge to minimize erosion in the vicinity of the terminal structure.

OVERFLOW STRUCTURES

Overflow structures should be designed to permit operation of the lagoon at selected water depths. The outlet structure should permit lowering the water level at a rate of at least 1 foot per week while the facility receiving its normal load. It should be of adequate size and suitable construction to permit easy access and normal maintenance operation. It is desirable that provision be made for complete draining of the lagoon.

During ice-free periods, discharge should be taken near, but below, the water surface. This releases effluent of the highest quality, and insures retention of floating solids. For operation during periods of ice cover and ice formation, the discharge is usually from a point substantially farther below the surface. However, some States have successfully used surface overflow pipes during prolonged freezing. Overflow structures generally comparable to a sewer manhole are most frequently employed, with selective level discharge facilitated through valved piping or other adjustable overflow devices. Stop planks of creosoted lumber have been successfully used in some cases.

Overflow lines should be vented if the design would otherwise permit siphoning. The overflow and outlet structure should be designed to meet the needs of the individual installation, with due consideration to the plan of operation. For "flow-through" lagoons the maximum rate of effluent discharge is considerably less than the rate of peak sewage flow, because of lagoon losses and the leveling out of peak flows.

INTERCONNECTING PIPING

Interconnecting piping for multiple unit installations should be of suitable materials and properly located so as to facilitate maximum retention in the facility. In some States, cast iron is specified for interconnecting piping. Valving or other arrangement to regulate flow between structures is recommended. It is desirable that each unit of a multiple unit installation be equipped for flexible depth control. The influent pipe to the secondary unit should discharge horizontally at or near the lagoon bottom so as to minimize need for erosion control measures. The inlet to secondary units can be located as near the dike as construction permits. If operation in parallel is to be considered, inlets should be designed as though each unit were to be operated as a primary unit.

INDUSTRIAL WASTE

Lagoons may be used for treating industrial wastes that are amenable to biological treatment, or a mixture of organic industrial wastes and domestic sewage. Installations are now successfully serving oil refineries, slaughter houses, dairy and creamery establishments, poultry processing plants, and rendering plants. Special study should be given the industrial wastes whenever they constitute a significant portion of the total load. Recommendations for loading and area, included in the preceding paragraphs, may be used to guide loading and area of facilities receiving industrial wastes. Possible toxic effects of industrial wastes should not be overlooked Toxic materials in concentration that would interfere with other biological sewage treatment processes should be handled in lagoons only after thorough study and evaluation.

Relatively little experience is available in the sealing of lagoons where high seepage rates are expected. Some clogging of permeable soil results from sewage solids, even though the sludge layer is extremely thin. Some lagoons have been built with multiple units to facilitate heavy original loadings. The entire sewage load is discharged to the smaller area, and when water holding capabilities are obtained, the flow is diverted to another unit.

Some use has been made of bentonite, asphaltic coating, clay blanket, and other sealing materials. Sealing by these methods can best be considered as a special problem for individual installations, with the consulting engineer basically responsible for adequate sealing to permit maintenance of satisfactory water levels.

INFLUENT LINES

The influent line to primary units should discharge far enough from any bank to insure minimum interference with normal circulation. For small installations, the discharge should be at the approximate center of the lagoon. For medium sized installations, there appears to be little advantage in locating the inlet more than 200 feet from the nearest bank, with 400 feet desirable for lagoons of 40 acres or more in area. Multiple inlets appear to have some advantage in dispersing solids uniformly throughout the lagoon, particularly in large installations.

Gravity inlets to primary units should slope on a uniform grade from the manhole at the terminus of the outfall sewer to a point approximately one pipe diameter below the toe of the inner or waterside slope of the dike. From this point the pipe is usually laid on a zero grade to the point of discharge, with the top of the pipe being slightly below the average elevation of the lagoon floor. Placing the bottom of the pipe on the lagoon floor, the use of earthen dikes, piling or other pipe supports, or the use of shallow dike formed areas around the inlet are not recommended, as there is some evidence that this may interfere with normal circulation.

Gravity lines and inverted syphons have been successfully used in many installations to discharge untreated sewage to primary units. Submerged portions of the influent line should be considered as under slight pressure, with appropriate materials and methods of construction. The size of the line should not be reduced along the submerged portion. Materials generally accepted for underground use may warrant consideration for use as gravity influent lines. Consideration should be given to the possibility of septicity, soft foundations, ice cover, and other loading problems.

The influent line may advantageously discharge horizontally, into a shallow, saucer shaped depression. This depression should have a minimum depth equivalent to the outer diameter of the pipe and a maximum depth of the pipe diameter plus one foot, with a radius varying from 25-100 feet depending on the size of the unit. The depression, intended only to facilitate submergence of sewage solids while the lagoon area is becoming saturated and covered with liquid, is particularly important for installations serving new sewer systems.

MISCELLANEOUS

Embankments should be seeded along the outer slope, the top, and along the inner slope to the normal water line. This minimizes erosion, facilitates weed control, and permits the maintenance necessary for good appearance. Alfalfa and similar long rooted crops should not be used. The County

Agricultural Extension Agent can usually advise of a hardy, locally suited permanent grass which will not interfere with the water holding capacity of the dike.

Riprap or other protection is warranted only under unusual conditions, such as protection of dikes from erosion due to severe flooding of the adjacent watercourse, or extremely severe wave action. Possibility of floods should be considered as lagoon dikes, like other earthen embankments, would be subject to flood damage.

The lagoon area should be enclosed with a suitable fence to preclude entrance of livestock and to discourage trespassing. Fences consisting of 3 or 4 strands of tightly stretched barbed wire have been found to facilitate mowing and other maintenance operations, and otherwise to be completely satisfactory unless swine or poultry have access to the area. For lagoons serving schools, resorts, or similar facilities, chain link or other special fencing may merit consideration.

At least one vehicle access gate should be provided.

The nature of the facility should be clearly designated through appropriate signs properly located at suitable intervals along the fence. The signs need only designate that the facility is a sewage treatment device and advise against trespassing.

For lagoons serving combined sewer systems, suitable grit removal facilities may be appropriate. Excessive grit may result in interference with circulation or discharge, through excessive accumulation of heavy material at the point of inlet discharge.

Study and evaluation of lagoons may be greatly expedited by providing a flow measuring device for influent and effluent. These devices need not provide continuous measurement, and may be quite inexpensive. For example, a manhole on the incoming sewer and one in the lagoon overflow line may be equipped so that a weir plate can be easily slipped into place during periods of flow measurement. A uniform receptacle for the weir plate will permit the State Agency to provide standard weir plates to expedite special studies. Flow measuring units should be located as close to the lagoon facility as feasible and practicable, but should not be located in submerged portions of a sewer.

Soil sterilization along the shallow water portion of the dikes has been found to be effective in controlling weeds in Kansas. The sterilizer, to be effective, should be resistant to leaching and toxic to weeds but not to algae. Application is made by power spray prior to filling of the lagoon.

POND TREATMENT OF MEAT PACKING PLANT WASTES

F. W. Sollo*

Oxidation ponds have become a very common method of sewage treatment for small communities. Little has been reported, however, on the use of these devices for the somewhat stronger wastes of the meat packing industry. Over a period of ten years, we have gained some experience with the use of ponds for this application, and feel that they have certain advantages where sufficient space is available and where the climate is suitable.

In 1951, a problem confronted Swift & Company at its plant near Moultrie, Georgia. The waste from this plant was discharged to a small stream which was essentially dry for several months of each year. A chemical treatment plant had been provided but did not produce the required degree of treatment. Unsatisfactory conditions prevailed throughout the dry summer months.

At that time, the use of oxidation ponds had been reported for a number of municipalities and army installations (1, 2, 3). It appeared that this method of treatment offered the advantages of a low investment or construction cost, simplicity of operation, and production of an effluent which was stable even with no dilution. On the other hand, the reported loadings, in the range of 50 lbs. of BOD per acre per day, indicated that large areas of level land would be required. In addition, there was no reported experience with this method for meat packing wastes. To evaluate the method, it was decided to construct a pilot scale pond in connection with our plant at Moultrie.

In the course of preliminary laboratory tests, it was found that ponds could be operated anaerobically without producing objectionable odors. The potential loading and BOD reduction per unit area in anaerobic ponds appeared to be considerably higher than that possible for oxidation ponds. This greater efficiency was expected, and a similar finding had been reported in the literature. (3) The absence of odor, at least of an offensive character, had not been anticipated. In view of the favorable laboratory experience, an anaerobic pond was also constructed for test purposes at Moultrie.

PILOT SCALE TEST

The first anaerobic pond had a capacity of 8,000 gallons and was approximately 5 ft. deep. The waste was added near the bottom at one end of the pond, and the effluent was taken off about a foot below the surface, near the opposite end. Digested sludge from a municipal treatment plant was added initially to obtain the desired fermentation.

A number of operating difficulties were encountered, due to the small size of the pond and the small waste flow required. Sedimentation with a very short detention period, and grease removal, were applied to the influent, but occasionally solids of sufficient size to interfere with the pumps or measuring devices would pass the pretreatment facilities. These were the only problems which arose, and there appeared to be no objectionable odor.

Over a period of three months, this pond produced an average BOD reduction of 78.6%, with an influent BOD of 1680 mg. per liter, pond temperature of 72° F., and a detention period of 4.4 days.

The oxidation pond had an area of 0.53 acres and was approximately 3 feet deep. A recirculation system was provided which sprayed a mixture of the raw waste and the pond contents through a number of nozzles. Recirculation was maintained at 100 gallons per minute continuously. This served to distribute the load over the pond surface and provided some degree of aeration. A heavy BOD load was maintained with the object of determining the maximum possible loading.

---

*Sanitary Engineer, Swift & Co., Chicago, Illinois. Also presented at the 15th Annual Purdue Industrial Waste Conference, May 3, 4, and 5, 1960.

Over a three month period this pond produced a 90% BOD reduction with an influent BOD of 1450 mg. per liter, detention period of 50 days, and a BOD loading of 243 lbs. per acre per day. The effluent was green and rather turbid, due to the unicellular algae produced. Oxygen concentrations far above saturation were observed near the pond surface during daylight hours, although none was found below a depth of 18 to 24 inches even in daylight, and that in the surface layer was dissipated rapidly as light intensity decreased.

From these tests it appeared that the oxidation pond could handle loadings somewhat higher than were generally being used, and would produce a stable effluent. On the other hand, the anaerobic pond did not produce a stable effluent but was far more efficient in BOD reduction per unit area. Thus a combination of these ponds, operating in series, was an obvious choice. To be certain that the effluent from an anaerobic pond could be handled with no special problems in the oxidation pond, our facilities were modified to permit a test with series operation.

A portion of the previous oxidation pond was dammed off for use as an anaerobic pond. (Fig 8) This section was approximately 50 feet square and had a capacity of 100,000 gallons. The oxidation pond was reduced to 0.40 acres by this change. Recirculation was continued and in the oxidation pond but the spray nozzles were eliminated. Thus distribution of the load was maintained, but the aeration formerly provided was eliminated. An appreciable power saving appeared possible by this change.

The ponds were operated in this manner for a period of 11 months. Typical operating data are given in Table 28.

The BOD of the final effluent in these tests varied from 35 to 270 mg. per liter. With other methods of treatment this effluent would be considered unsatisfactory for discharge to a dry stream bed. It appeared unlikely, however, that any nuisance would be caused in a stream by this effluent as long as the pond itself remained stable. Dilution in the stream, if any were available, and reaeration, should improve conditions over those prevailing in the pond. For these reasons, it was thought that this effluent should be satisfactory.

BOD data may be misleading on such an effluent, since the algae will consume oxygen in darkness as in the normal BOD test, but will produce oxygen with sufficient light. Our data were also affected by the

TABLE 28

PONDS IN SERIES

Average Data, 6/1/62 to 3/28/53

Anaerobic Pond

Detention--------- 4.6 days
BOD Loading------- 11.2 lbs. per 1000 cu.ft. per day
Influent BOD------ 820 mg. per liter
Effluent BOD------ 284 mg. per liter
BOD reduction----- 65.4%

Oxidation Pond

Detention--------- 18.4 days
BOD Loading------- 130 lbs. per acre per day
Influent BOD------ 284 mg. per liter
Effluent BOD------ 116 mg. per liter
BOD reduction----- 59.2%

fact that the samples were frozen for preservation, killing most of the algae. Unfrozen samples, diluted as in the BOD test, but incubated in daylight, produced oxygen rather than exerting a demand. The same samples, with normal incubation, exerted a normal oxygen demand.

FULL SCALE INSTALLATION

With the data obtained in these tests, it was decided to proceed with installation of a pond system of treatment for our Moultrie plant. This was completed in 1955, operation starting in November.

The existing chemical treatment plant was left intact, but chemical addition was stopped. Thus these facilities served for primary sedimentation and grease recovery.

The anaerobic pond, shown in Figure 9, is 192 ft. x 320 ft. at the surface, and has a 14 ft. water depth. The banks are of earth construction and have a slope of 1 to 3. The approximate volume of this pond is 4.2 million gallons. A concrete pad was provided at the water line to prevent erosion and weed growth.

As in the pilot scale ponds, the waste is introduced near the bottom at one end and the effluent removed at the other end. Underflow baffles were profided at the effluent weirs to prevent loss of floating solids. Sludge is recirculated from the pond bottom and mixed with the influent waste to obtain maximum possible contact.

No heating facilities were provided due to the mild climate, and four years of successful operation indicates that heat is not required. However, occasional extended cold weather has resulted in somewhat reduced efficiency. The effect on efficiency is noted when the pond temperature remains below 75° F. for a prolonged period.

The oxidation pond, shown in Figure 10, is irregularly shaped and has a total surface area of 19.2 acres and a depth of 3 feet. Here again, the banks are protected at the water level with a concrete pad. The waste entering this pond consists of the effluent from the anaerobic pond, condenser water, and storm water.

The waste is mixed with the recirculated flow of pond contents and distributed along the west bank by a flume and series of twelve weirs. Effluent is removed through four overflow channels in the east bank and the recirculated flow is drawn from the southeast corner through a channel along the south edge to the pumping station at the southwest corner. A pumping capacity of 4500 gallons per minute was provided for recirculation, (three 1500 gallon per minute pumps) but only one of the three pumps is operated under normal conditions.

In Table 29, we have listed the BOD values for the first four years of operation averaged over each period of six months.

The table shows an obvious improvement in results, especially in the anaerobic pond, through the first eighteen months. This trend actually extended through Octo-

TABLE 29

AVERAGE BOD VALUES

	Raw Waste	Anaerobic Effluent	Oxidation Pond Influent	Final Effluent
Jan.-June, 1956	1005	454	345	127
Jul.-Dec., 1956	1390	109	103	40
Jan.-June, 1957	1110	55	95	46
Jul.-Dec., 1957	1068	105	124	51
Jan.-June, 1958	1052	141	130	92
Jul.-Dec., 1958	1010	83	63	61
Jan.-June, 1959	879	96	66	43
July-Dec., 1959	1250	230	137	73

ber, 1957. During November and December, unusually cold weather prevailed and the efficiency of the process deteriorated to some extent.

Stream conditions have been entirely satisfactory below our outfall since installation of these ponds. During periods of low flow, the stream has a distinct green color for the first mile or two but no odors have ever been noted and the color disappears in a short distance.

Operation is very simple. The only labor required is the occasional maintenance and greasing of pumps, cleaning bar screens, and caring for the grounds. This, of course, is exclusive of labor for operation of the primary facilities. Routine analyses have been continued as a precaution against unforeseen difficulties.

SLUDGE ACCUMULATION

The pilot plant experience did not provide any reliable information as to sludge accumulation. It was anticipated that sludge would have to be removed from the anaerobic pond upon occasion but not from the oxidation pond.

After 2 1/2 years, it was found necessary to remove sludge from the anaerobic pond. The top level of the sludge layer was about 4 ft. below the surface, and sludge carry-over appeared certain in a short time. The surplus sludge was pumped to a nearby field where it dried without nuisance.

OTHER APPLICATIONS

In further tests, carried out in Iowa, it was found that the method could be applied in a fairly severe climate. An underwater burner was provided to heat the anaerobic pond, but no heat was provided in the oxidation pond.

Excellent results were obtained and for a small packing operation the method should be satisfactory. For a large operation the cost of heating the pond would probably make other methods more attractive.

The anaerobic pond has also been applied at another of our packing plants, located in North Carolina, as a pretreatment device. The pond reduces the BOD of the waste to approximately 100 mg. per liter before it is discharged to the municipal plant where it is given final treatment on trickling filters. In this case also, there was a gradual improvement in results during the first year of operation. Steam is injected as required to maintain a minimum of 75° F.

SUMMARY

A two-stage system of ponds has been applied to the treatment of meat packing plant wastes. Advantages are low investment cost, simplicity of operation and production of an effluent that is stable without dilution. The system has been applied in areas with a mild climate, and its greatest advantage is for this application, but it has also been found applicable in relatively severe climates.

BIBLIOGRAPHY

1. Caldwell, D. H., Sewage Works Jour., 18, 443-58 (1946)
2. Committee on Sanitary Engineering, N. R. C., Sewage Works Jour., 18, 1023-6 (1946)
3. Parker, C. D., Jones, H. L., and Taylor, W.S., Sewage and Ind. Wastes 22, 760-75 (1950)

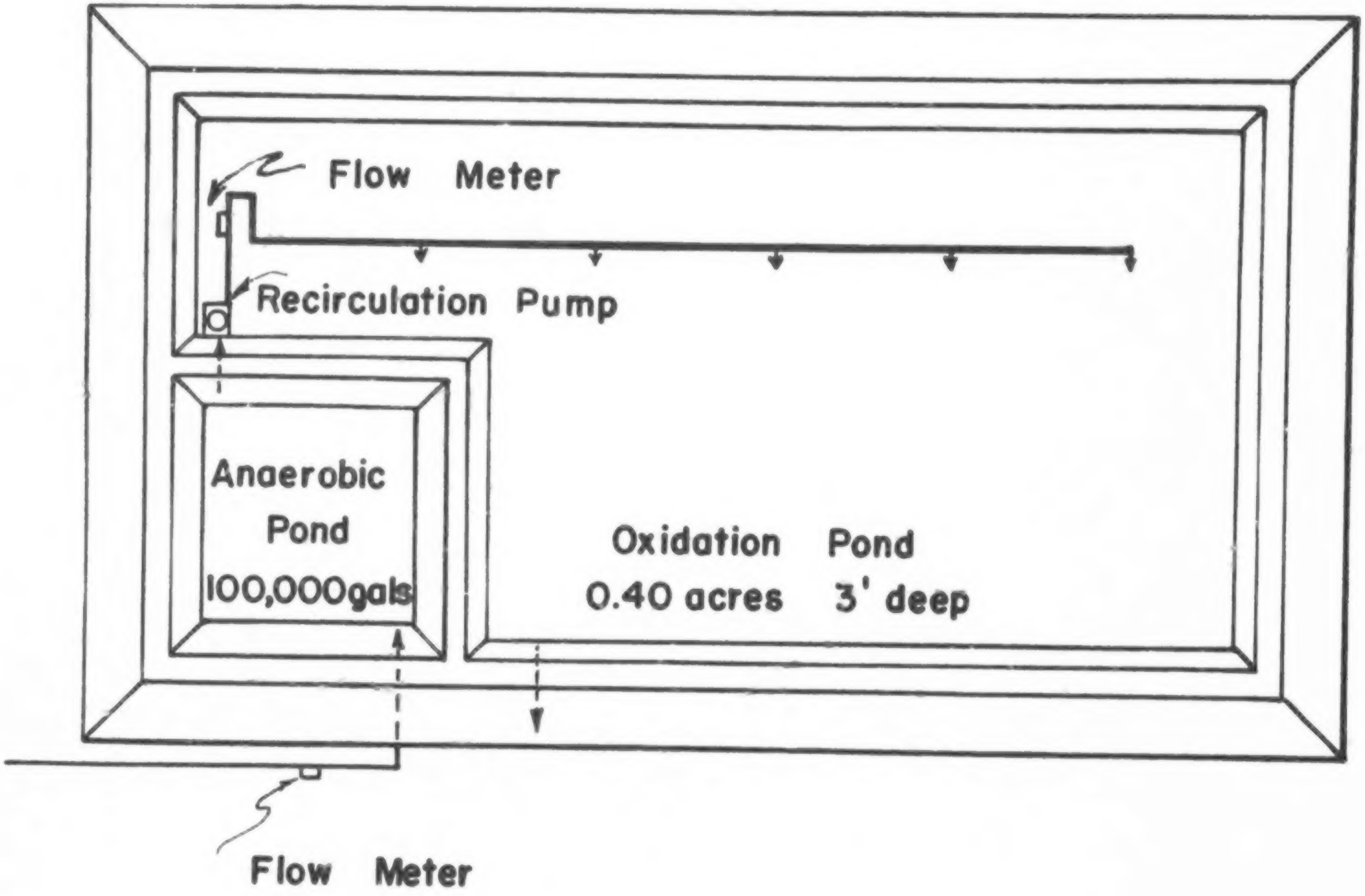
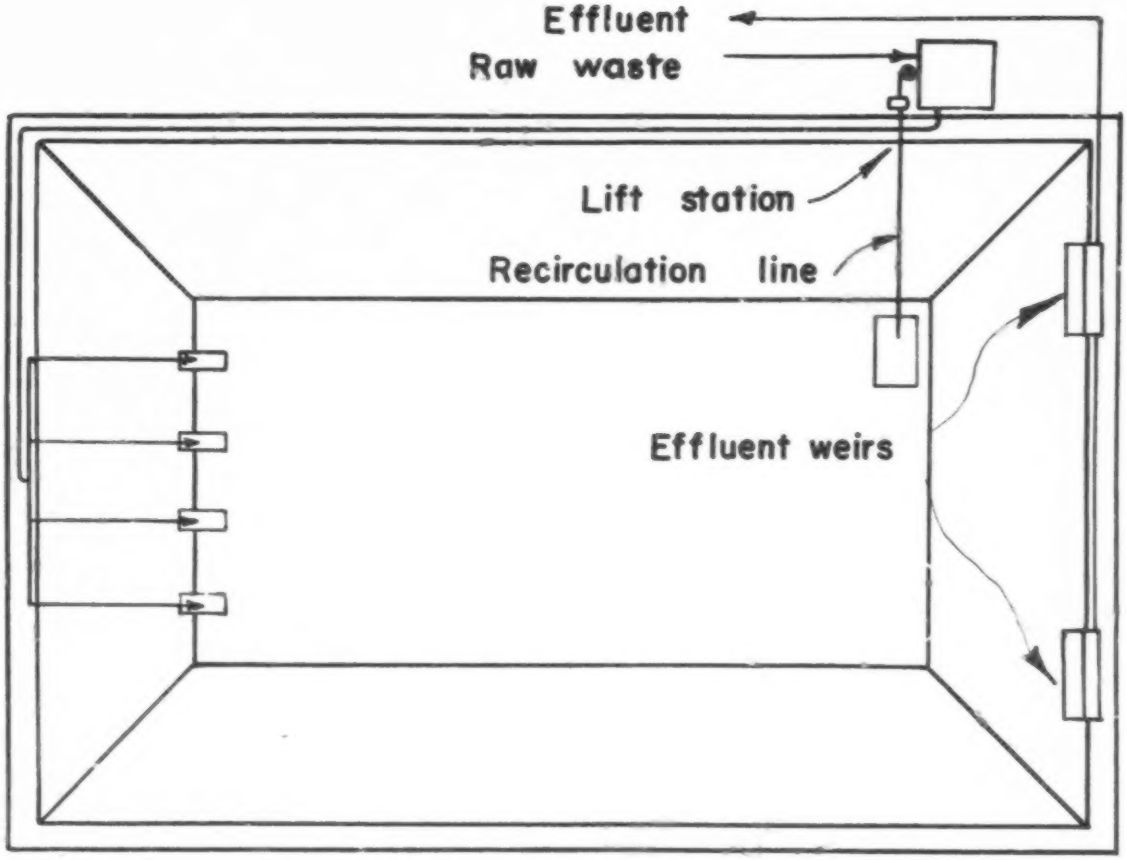

Flow Meter
Recirculation Pump
Anaerobic
Pond
100,000gals
Oxidation Pond
0.40 acres 3' deep
Flow Meter

FIGURE 8

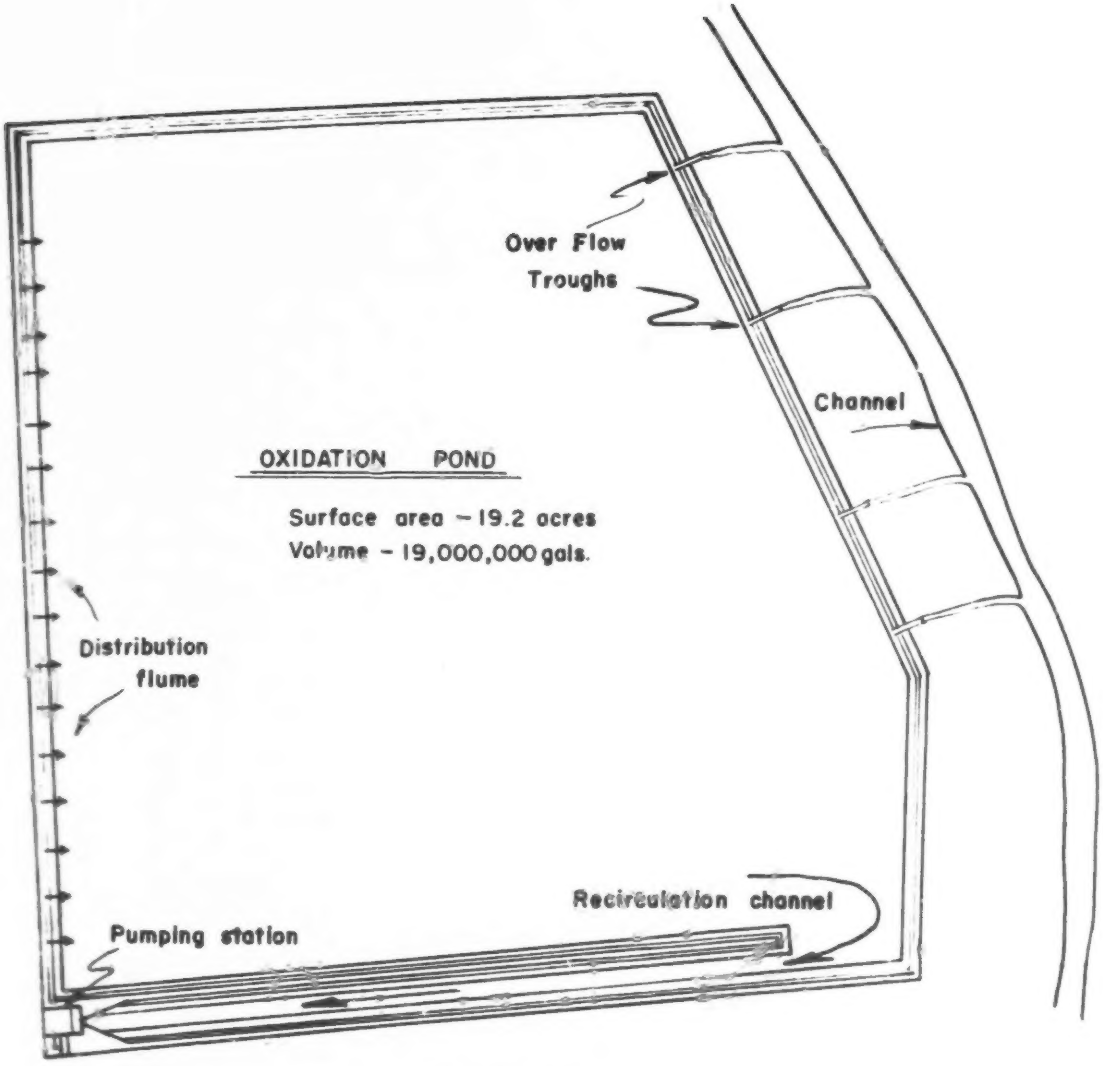
PONDS IN SERIES


Effluent
Raw waste
Lift station
Recirculation line
Effluent weirs

ANAEROBIC POND

192' x 320' x 14'
Vol. 4.6 mil. gal.

FIGURE 9



Over Flow
Troughs
Channel
OXIDATION POND
Surface area - 19.2 acres
Volume - 19,000,000 gals.
Distribution
flume
Recirculation channel
Pumping station

FIGURE 10

DEVELOPMENT AND ACCEPTANCE OF LAGOONS IN MISSISSIPPI

J. E. Johnston*

From skepticism to enthusiasm -- those four words summarize the sewage lagoon story in Mississippi. The state health officer was skeptical when the lagoon idea was first presented to him; professional engineers in the state were dubious; municipal officials were likewise skeptical; and the public in some cases was almost hostile.

But somehow the lagoon idea as a solution to the sewage problems in our small towns had taken hold of us in the Division of Sanitary Engineering -- things we'd heard about it and read about it would not leave us in peace. Like the evangel stirred by a spirit outside himself, we could not rest. And I'm here to share our story with you -- because in introducing the lagoon in new areas some of you will perhaps encounter this same attitude of skepticism that we had to combat. But my advice to you is simply this: "Don't give up." It won't be easy to hold out, but on your side will be two unshakable allies: first, the engineering and chemical principles involved; and second, the proven experience of the workability and practicality of the lagoons. First of all you will need a well-grounded belief in the idea. I warn you, however, conviction alone will not be enough; coupled with it, you'll need tenacity also.

As you know, Mississippi has been an agricultural state with most of the population living on farms and a comparatively few people living in the approximately 270 towns. With the economy of the state geared to agriculture as it had long been, there had been little need for larger centers of population. But with the development of the industrial programs of the state and the mechanization of farm operations in the last two decades, our small towns began to attract more people. Accordingly, as the towns began to grow, there was an increased need for sewage facilities.

In 1955 in Mississippi, there were only some 24 municipalities with conventional sewage treatment plants. To make matters worse, most of these were not operated efficiently. A number of towns had sewage collecting systems, but discharged raw sewage or septic tank effluent into streams - some of which did not have sufficient flow for adequate dilution. This was the condition that confronted us when I became Director of Sanitary Engineering of the State Board of Health.

For a number of years we had been aware of the use of lagoons, but gave them little consideration until the Dakotas began to use them so effectively. We learned of the good results of the Dakotas' lagoons when we began to search for an answer to the ever-increasing problem of sewage treatment for small municipalities. As we discussed their use in Mississippi, first in an almost joking manner, our interests grew. After it became evident that lagoons might be the answer to our problems, we began to seriously study all available information - and then to seriously talk lagoons. In professional engineering circles, instead of encouraging us, practicing engineers tried to throw cold water on us. Some even went so far as to come to me, or send my friends to me, with the warning, "You're going to get in trouble."

However, obsessed with the idea that the lagoon held the answer to many of our acute sewage problems and our responsibility in doing something about it, we requested the Public Health Service to send to Mississippi someone who was thoroughly familiar with the stabilization ponds to discuss them with us. Two specialists came to our state on January 25, 1956 -- W. W. Towne, Chief of Water Pollution Control of the Robert A. Taft Sanitary Engineering Center (whom you heard yesterday), and L. A. Young, Associate Regional Engineer of Public Health Service, Atlanta. After the assurance of these two experts that the ponds would probably work better in Mississippi than in the mid-western states where they freeze over in winter, our enthusiasm rose. But even these specialists could not completely dispel the skepticism of the state health officer. When he was told that a hurried call had been issued for professional engineers in our capital city and vicinity to come to hear the story the Public Health Service specialists had to tell, he said: "I hope you don't get the Board of Health in trouble."

---

*Director, Sanitary Engineering, Mississippi State Board of Health, Jackson, Mississippi.

Thirteen engineers and chemists answered the call; and to a man they became not only interested, but most of them enthusiastic about the possibilities of the lagoon in our state. At the close of the meeting, they suggested that I go to Missouri and see the lagoons in operation. Even though the state health officer did not approve my going, not to be deterred, early in March after the ice had melted, I went to Missouri *sub rosa*. I never shall forget the courtesies of Albert Happy and his staff, Glen Hopkins, and Joe Neel. Everything I saw in Montgomery City, Paris, Perry and the Kansas City area exceeded my expectation. Convinced that the State Board of Health should recommend the lagoon, I turned homeward with my mind made up and a jug of lagoon water in my car! That jug of water was more convincing than words.

Recommendation of the lagoon by the State Board of Health was forthcoming. The design criteria developed in the mid-west were adopted by our agency, with the exception of the loading factor which was set at 35 pounds of BOD per acre. All engineers concerned with this type of work were contacted and our design criteria discussed with them.

Our first target was Prentiss, a fast-developing town in South Mississippi. The main part of that town was served by an Imhoff tank, which was over-loaded and very poorly maintained. The western section was developing and needed service, but a pumping station would be required. Then it was that the consulting engineer, in cooperation with the State Board of Health, in conference with the city officials convinced them that the lagoon could best solve their sewage problem.

The Prentiss lagoon was put in operation on October 1, 1956. Never shall I forget the day I took the state health officer down to see this "curiosity." On the trip was also the assistant health officer, who is now state health officer and supporting the program with a great deal of enthusiasm. We had hardly gotten outside the city limits of our 60-mile trip when they began to rib me, saying they could already smell the lagoon. I took the ribbing of my two superiors as long as I could and said, "All right, gentlemen, just let up until we get there. If there's any sewage odor at all from the lagoon, the drinks are on me." When we got to the site, I took a bucket and caught it about half full of the effluent from the lagoon and handed it to the state health officer. He sloshed the water around, stuck his nose in the bucket, sniffed and sniffed again. "I'll buy the drinks," he said, the last vestige of skepticism gone!

Continuously for almost four years now this lagoon has been in operation. What has been its operational history? How has it been accepted by the people? To get the answer let me quote from a recent report to us by the mayor of the town:

"I am happy to inform you that it is doing a perfect job. It has been in operation nearly four years and has done better this year that it did the first year, even tho it has had a small increase in load. I can safely say that for a small town where land is reasonable, that this is the best solution, as the cost of construction is very reasonable.

"We have approximately 400 people per acre and it is doing perfectly, other than just a little floating matter on top of the water. You can hardly recognize it as being anything but a fish pond since it doesn't have any odor at all - in fact, there are millions of small fish in it."

But back to the development of the lagoon in Mississippi. From near and far came consulting engineers, city officials, developers, and university professors to see the Prentiss lagoon - the first sewage lagoon to be constructed in the southeast. They came from Florida, Georgia, Alabama, South Carolina, Tennessee, Louisiana, Arkansas, and Virginia. Requests began to come from city officials and civic clubs for us to talk to them about lagoons.

Even though the State Board of Health has promoted the lagoons by all mass media available - the press, television, exhibits, and state-level meetings, from the very beginning the decision was made to let the promotion program on the local level be through the practicing consulting engineer. We declined to accept invitations to discuss lagoons with any local group unless the invitation came through an engineer. This decision, wise as it was, had a two-fold basis: first, we wanted to keep the program in the hands of the engineers; and second, our staff was too limited to spend time providing programs for some civic club. If the municipality was interested enough to employ an engineer, we felt that it meant business and we went early and late from one side of the state to the other to talk lagoons. The wisdom of our decision to work through the practicing engineers has time and again been demonstrated; it is also substantiated by a letter that came to our office recently from Eugene Thomas, President of the Mississippi Society of Professional Engineers:

"It has been my privilege since 1956 to follow the development of sewage lagoons in Mississippi, and since I believe this development has made a real contribution toward the general improvement of sanitary conditions in the smaller communities, I would like to congratulate you on the manner in which your office has handled this relatively new idea in our State.

"Your splendid cooperation with the practicing engineers of Mississippi is something that every member of the profession appreciates, and I feel that the contribution made by your office in improving conditions throughout the State is worthy of continued confidence. I know for a fact that you have in all cases worked through the engineering profession in this matter rather than through other local officials.

"This is an approach which I feel is fitting and proper and which not only provides an opportunity for engineers to participate in these developments, but also contributes greatly to an orderly method of community improvement.

"If there is anything the Society can do to assist you in the important work handled by your office, I am sure we will be most happy to oblige."

In less than a year after the first lagoon began operation, five other towns had constructed them; and today there are over 60 lagoons in operation and 25 under construction or being planned by muncipalities and institutions.

A year after the first sewage lagoon was constructed the lagoon program was "on the road." Skepticism was giving way to enthusiasm. Private developers and schools wanted to use them. But ever cautious, the State Board of Health withheld approval in such places because we did not want the program to get out of hand and have some installations that might possibly give the program a "black eye."

However, after a demanding letter from the State Superintendent of Education to permit the use of lagoons in rural schools and a promise from him that his staff would give full cooperation in maintaining them, especially by maintaining a satisfactory water level during the summer months, public health approval was given. Ten schools are now using sewage lagoons.

Two years ago we began approving them for private developments, such as subdivisions. We now have twelve such developments using them.

The developers of Skyway Hills, across the river from Mississippi's capitol city, says that their entire staff takes pride in being the first in the state to provide a lagoon. From the builder's viewpoint they cite the following advantages of the lagoon:

"The fact that our subdivision has this type of sewage system has been the main feature of our sales campaign and our sales campaign has been most effective."

The developers of McLaurin Heights, a subdivision in Rankin County, wrote us on recent date:

"We wish to express our complete satisfaction in regard to the lagoon system of sanitary sewerage disposal. Before a sewerage system was installed in McLaurin Heights Subdivision, Rankin County, Mississippi, approximately 50% (in numbers) and 75% (in cost) of our warranty complaints were due to septic tanks. Although we exhausted every known means of trying to remedy septic tank malfunctions before the end of the one year warranty period, still there were several septic tank systems that were not properly functioning, which of course left dissatisfaction in those house purchasers.

"We have found, although the lagoon type sewerage system takes a great deal larger initial investment, that by the time a subdivision is 'built out,' the average cost per house is less than the original installation cost of a septic tank system.

"We appreciate the assistance given to us by the Health Department and the forward looking approach of the trial of these lagoon systems which will greatly aid developers, builders and home owners in outlying areas."

Mr. J. W. Underwood of Jackson states: "The lagoon is a most satisfactory sewerare treatment method.... In the instance of our 700 home Canton Avenue Estates, we abandoned a conventional mechanical treatment plant that was only about 5 years old and installed lagoons to treat the sewerage for the then existing houses as well as future ones. It has definitely been more economical for us to do this."

I would not mislead you into believing that the acceptance of the lagoon in Mississippi came "over night." Acceptability of the lagoon has been a developing attitude that has increased steadily through the last five years. Consulting engineers, equipment manufacturers, city officials, financial institutions, and finally the general public, although doubtful at first, have come to accept lagoons with enthusiasm.

To illustrate this general acceptance, I would like to read some statements taken from letters we have received in our office:

W. E. Johnson, Consulting Engineer, Jackson, Mississippi, wrote: "Without any reservation, I endorse and recommend the lagoon treatment where possible."

James F. Smith, Mayor, Wiggins, Mississippi, said in part: "The lakes are placid and pleasing to the eye; they are habitats for water fowl.... The people of the Town are pleased with them."

H. M. Ludlow, Manufacturer's Representative, Jackson, Mississippi, says business has increased, "a good percentage of which can be directly attributed to sales created by the installation of the many Oxidation Ponds in areas and communities who otherwise were financially unable to purchase other types, or mechanically operated Treatment Plants."

From the Rankin County Bank, President J. C. Murray, who financed some of the developers in this county using lagoons, wrote of the successful operation of several lagoons in the county, and said: "We much prefer to make loans on property having a sewer system than on property with septic tanks.... We believe that a sewer system with a lagoon or lagoons is as good as one with a treating plant, and we do not hesitate to recommend this type of sewer system."

From the Town of Bay Springs, after over three years of experience with a lagoon, Mayor S. F. Thigpen, Jr. wrote: "The operation is still perfect and the cost has not exceeded $60 a year.... This is the only thing public or personal that I have ever had anything to do with that has so greatly exceeded what was expected of it."

From the Hinds County Water Company, which first entered the sewage business three years ago, President Garner M. Lester wrote: "We now operate three lagoons.... Since this was our first venture into the use of sewage disposal units of this kind, we have watched the operation very carefully. Few of our customers and friends had ever heard of, let alone seen, a lagoon and naturally they were skeptical. They have operated so successfully that now uncertainty has turned into confidence.... We thought you would be interested in our operations since you worked so closely with us in the beginning...."

From the Town of Crenshaw, three weeks after hook-ups were made to the lagoon, Mayor C. B. Goodwin, reported to us: "As you know, our Town being in the Mississippi Delta is very flat, and those homes which have been connected for only a short time have eliminated the water soaked conditions of their yards and water filled ditches of the foul polluted excess water from the old septic tanks. We wish to thank you at this time for your aid in helping the Town of Crenshaw complete such a needed and valuable project for the community."

From the Town of Fayette after two years' use of the lagoon, R. J. Allen, Mayor, and B. J. Scarborough, Sanitation Committee Chairman, wrote: "We have encountered no defects in or dissatisfaction with the lagoon system and .... recommend this type system without reservations."

From J. B. Bell, the Mayor of Hernando, where a lagoon was constructed in 1957 to replace an outdated and inadequate Imhoff tank: "The governing authorities and the residents of Hernando have been very pleased with the operation of their treatment lagoon, and the Town has on the drawing boards new plans for three additional sewage treatment lagoons.... The lagoon in operation has been perfectly satisfactory in all respects.... The Town's maintenance has been at a minimum consisting so far only of keeping the grass cut.... We had a good crop of fish coming on in the lagoon, but a cotton dusting plane got loose over it and we lost our crop of fish."

From Houston where a 15-acre lagoon has been in operation since August, 1957, Mayor J. H. Miller wrote: "It has proven very satisfactory since the first day of operation, and looks more like a recreational place than a disposal unit."

From the City of Starkville, the home of Mississippi State University, Mayor Hayden H. Reynolds stated: "We put two twenty-five (25) acre cells into service in September 1959 and they have given us satisfaction far beyond expectation. We seem to be getting 100% treatment from them and are highly pleased with their operation.... The general public who have visited the project have accepted them very enthusiastically and feel they are a credit to our city. College boys from Mississippi State University say it is a hunter's paradise...."

From the Town of Poplarville, Mayor Pat Hyde reported: "We have had our sewer lagoon in operation for approximately eighteen months and have found it to be the answer to the sewage problem in the smaller cities and towns.... When we first talked to our people about a lagoon, they were a little skeptical as it was something that they weren't familiar with. I was about as skeptical as anyone in town...."

From the City of Aberdeen, one week after two lagoons were put in operation, Mayor George W. Howell, Jr., wrote us: "The City of Aberdeen has been dumping its sewage into the Tombigbee River for sixty years or more; and, this practice was stopped for the first time when the lagoons were put into use. This fact alone made the lagoons popular from the very start with the general public. Property owners have cooperated, and we had no difficulty in securing land for the lagoons where we wanted them located and for very reasonable prices.

"Since we quit dumping sewage in the river, a group of sports enthusiasts here have built a boat landing on the river just off East Commerce Street and have gone in for boating...."

In speaking of the development of lagoons in our state, we must not fail to point out that two experimental sewage lagoons were put into operation on the campus at Mississippi State University on August 15, 1958, in cooperation with the State Board of Health. Experiments, in the main, have sought the answers to three problems: (1) How to control blue-green algae; (2) What is the optimum depth; (3) What is the optimum surface loading. While a great deal of data have been collected, no definite conclusions have been reached. The micro-biology department has also been interested in these experimental lagoons and has demonstrated that organisms of the genus Salmonella can survive passage through the lagoon.

The only trouble that we have encountered in lagoon operational experience in our state has been the development of blue-green algae in extremely hot weather. As you know, dead blue-green algae give off a distinct pigpen odor. The first complaint of odor to reach us came in July 1958 from a two-year old lagoon. The Public Health Service office in Cincinnati answered our emergency call by sending in a specialist the next day by plane, who identified the mass of dead blue-green algae as the mischief maker. However, it soon disappeared and there was no further trouble that season.

The following summer, under the heat of July's sun, the same lagoon developed the same pigpen odor, as well as two other lagoons in different parts of the state. The first complaint came from the mayor of a nearby town, and it was suggested to him over the telephone that he have the scum broken up with long poles or boards and that it might settle out. When I left the office that afternoon, I drove to the town to see if beating up the scum was getting results. I soon saw that this method was too slow to be successful. I had an inspiration: Why not put a boat with outboard motor on the lagoon to beat up the mass? This we did, and in a very short time the lagoon surface was clear and the pigpen odor disappeared. During this summer several lagoons have developed the pigpen odor; and in each case a boat and outboard motor have soon had the condition under control.

The question of mosquito breeding kept cropping up as we talked with people about lagoons. But apparently Mississippi lagoons are not a very suitable place for mosquitoes to breed. In July and in September of 1958 Leslie D. Beadle, Chief Biologist, Water Resources Activities, Public Health Service, (who will be heard later), made a mosquito survey of nine of our lagoons that had been in operation for the second summer. Mosquito breeding was detected only in the Prentiss lagoon. This lagoon showed moderate breeding in July and light breeding in September, while the swampy area near the lagoon showed very heavy breeding. To date we have not had a single complaint about mosquito breeding in lagoons.

What, you might ask, has been the total effect of the development and acceptance of lagoons to date in Mississippi? And what is the future challenge to us?

These questions might best be answered by a letter that came to our state health officer a few weeks ago. It was from a man many of you know - Sam A. Thompson, Chairman of the Board of Water Commissioners of the State of Mississippi. He explained that he had just seen a newspaper clipping showing a picture of one of the state's latest sewage lagoons and was prompted to write a letter to the State Board of Health, which said in part:

"Mississippians have just cause to be proud of the leadership role that your agency has assumed in the program that is doing so much to upgrade the quality of the surface waters of our State.

"Since your Division of Sanitary Engineering introduced the sewage lagoons to Mississippi, the many towns that have taken advantage of the program have practically eliminated the once serious pollution problem in their vicinities.

"If you can keep up this good work for a few more years, our State will be able to make the maximum use of its water resources."

Our agency is resolute. In the days ahead with the special assistance of Public Health Service and through the stimulation from the pooling of ideas and experiences in groups such as this, we shall go forward.

USE OF SEWAGE PONDS IN ALBERTA, CANADA

By

H. L. Hogge and, S. L. Dobko*

The number of sewage ponds in use in Alberta has grown from one in 1947 to 114 in 1960. This extensive use is attributed to three main factors, viz. low construction and operating costs, effective treatment of sewage and the storage capacity which permits the effluent to be released at an appropriate time.

The design and use of ponds in Alberta is influenced to some extent by the climatic conditions experienced. Alberta is the most westerly of the three "prairie" provinces of Canada. The north and south boundaries are the 60th and 49th parallels of latitude respectively; the east boundary is the 110th meridian and the western one is the 120th meridian and in the south part the "Continental Divide" in the Rocky Mountains. The mountains to the west result in a relatively dry climate with the average annual precipitation ranging from 10 to 20 inches for most areas. The northerly position of the province means that winter temperatures are cold. The January average is 0 to 5 degrees Fahrenheit for all but extreme northern areas where it is 0 to minus 15 degrees. This results in a thick ice cover on sewage ponds during the winter and this, together with snow, excludes the sunlight necessary for oxygen production by the algae. Summer temperatures are moderate with the July average ranging from 55 to 65 degrees F. Winds are of a relatively uniform annual velocity of about 10 m. p. h., although the stronger winds are from the south west in southern areas and northwest to north in the northerly areas. Soil conditions are quite varied ranging from heavy clays to sandy and sandy silt. Percolation from the ponds is appreciable in only a few locations.

The population of Alberta was 1, 220, 611 in 1959 with 66% of the people residing in incorporated urban centres and 34% in rural areas. Some 96% of the urban population have public sewerage systems available through 187 systems. As mentioned above 114 of the sewerage systems use sewage ponds for their sewage disposal facilities. These are relatively recent installations, all within the past 15 years, and have been a factor in making sewerage systems possible, particularly for those communities not located near a river or lake.

The design and use of the ponds has undergone a number of changes which may be of interest to others.

The first ones were built mainly for storage purposes and were designed to store the sewage for one year. They were preceded by either a Septic tank or an Imhoff tank to remove solids and the accumulated effluent was released in the spring with the annual run-off. At this time of year there was a maximum amount of dilution to carry away the effluent and also it is before the farmers are working the fields crossed by the small drainage courses.

A second phase was the use of open pits, having a detention time of one to two weeks to take the place of the primary sewage treatment plants both in preceding the storage ponds and also as the only treatment where primary treatment was all that was necessary.

A third phase in the use of sewage ponds was the elimination of pretreatment units preceding the storage ponds and using only the storage ponds both for treatment and storage. These were mainly constructed in single units even as large as thirty and fifty acres.

---

*Respectively Director Division of Sanitary Engineering and Engineer, Sewage Pond Study Project Division of Sanitary Engineer, Alberta Department of Public Health.

The fourth phase that we are now starting in Alberta, and which we believe will be of most interest, places emphasis on the treatment efficiency of the short detention ponds and the added advantages of having the long detention ponds constructed in units arranged for series flow of the sewage. Very briefly, we are recommending the following type of pond system where complete sewage treatment and also intermittent release of the effluent is necessary:

1. Short Detention Ponds - Four ponds with a detention time of two to five days in each.
2. Long Detention Ponds - Two ponds with a detention time of three or six months in each.

This latest type of ponding system has been adopted this year on the basis of a two year study of the operations of different types of ponds. The study was undertaken as a research project financed by the Government of Canada, Department of Public Health in co-operation with the Department of Lands and Forests and the University of Alberta. A chemical engineer of the Department of Health made the field observations, collected all samples and analyzed the samples for physical, chemical and B. O. D. characteristics. The analyses were made in the Department of Health's Pollution Control Laboratory. Methods of analysis were those outlined in the 10th Edition of "Standard Methods for the Analysis of Water, Sewage and Industrial Wastes." A master's student in microbiology at the university under the direction of the Bacteriology Department made analysis for total aerobic and anaerobic bacteria and also for coliforms and algae. At this time, the master's thesis and the analysis of the data are incomplete.

The ponds selected for detailed study were those within 100 miles of Edmonton to enable sampling and analysis to be carried out in the same day. Also these ponds were representative of a variety of loading and design features. Five ponds were sampled approximately once a month for a 12 month period, a 24 hour composite of raw sewage made flow rates measured, and the chemical analysis of the community water supply obtained.

The statistics respecting loading and removal of B. O. D. and ammonia are quite interesting and are noted below in Table 30.

The long detention ponds of Holden and Lacombe, which are constructed in a single unit, gave removals of slightly better than 80% of the B. O. D. and 90% of the ammonia during the summer. In winter time the treatment starts to deteriorate soon after the ice cover forms, and remains at a lower level until spring. These two ponds are quite similar. However, the B. O. D. reductions in the winter were consistently different during both winters. The B. O. D. loading for Lacombe is slightly higher but would not be expected to be significant.

The Bruderheim pond operated poorly during the period of study and appeared to be affected by the wastes from the local cheese factory. The observed B. O. D. of the raw sewage was 394. However the summer B. O. D. of the pond average 465 and in the winter was 880 p. p. m. A Computation of the B. O. D. in the cheese washings for the plant indicated the average B. O. D. of the towns sewage would be increased 632 p. p. m. which would explain, at least to some extent, the high B. O. D.'s observed in the pond and most likely the poor functioning of the pond.

The ponds at Drayton Valley are constructed in three units and worked very efficiently during the summer. In addition to the B. O. D. and ammonia reductions the removal of coliforms was very good and the effluent in the third pond was clear. The treatment deteriorated during the winter season and remained at the lower level until spring.

The Short Detention Pond studied in detail was at Stony Plain. This system worked at about the same level throughout the year. The B. O. D. reduction of 70% particularly during the winter time is quite good and the installation is very inexpensive. This system was expanded to include a storage pond in 1959 and this appeared to work very well but sufficient tests were not carried out to determine it's efficiency.

The "Short Detention Ponds" were of particular interest to us because of their efficiency during the winter and we made surveys of five other installations. The statistics on these are included in 30A.

These ponds were all of the single unit type and are therefore not directly comparable to the Stony Plain installation, except to the first of the three units at Stony Plain.

TABLE 30

	Holden	Lacombe	Bruderheim	Drayton Valley				Stony Plain			
Populations (Served)	450	2,835	220	2,800				1,040			
Sewage:											
-Daily flow-gallons	28,500	110,000	20,000	242,000				76,000			
-Per capita g.p.d.	63.4	39.1	91.0	86.3				73			
-B.O.D.-lbs./cap./day	0.31	0.13	0.36	0.26				0.25			
Lagoons:											
-Type	Single	Single	Single	Triple				Triple			
				1	2	3	Total	1	2	3	Total
-Size-acres	7.2	16.6	3.7	9.2	5.8	7.8	22.8	.052	.052	.15	.254
-Detention Time-days	274	204	200	51.8	32.9	35.6	120.3	.93	.93	2.6	4.46
B.O.D. Loading-lb/acre/day	19.2	22.4	21.5	79.4	33.0	?	-	4920	3400	?	-
Treatment:											
1. B.O.D. Removal%											
(a) In summer	83	82	neg*			91		70			
(b) In winter	73	38	minus**			65		70			
2. Ammonia Reductions%											
(a) In summer	90	90	neg*			90		neg*			
(b) In winter	neg*	neg*	minus**			neg*		neg*			

*Indicates a negligible amount of change.
**Observed values were higher than those for raw sewage.

TABLE 30A

Municipality	Detention Time-Days	Population	Raw Sewage g.p.d.	B.O.D. p.p.m.	Pond Loading		B.O.D. Removal %
					lbs. B.O.D./ acre/day	lbs. B.O.D./ acre ft./day	
Calmar	4.7	738	35,100	615	1390	348	54.3
Myrnam	11.7	440	11,500	236	329	54.9	30.5
Thorsby	10.4	491	14,400	1125	2360	295	42.2
Two Hills	1.9	886	53,000	294	3870	215	15.7
Daysland	6.2	507	15,040	702	2620	455	47.8

Our tests showed a B. O. D. removal of 33% in the first of the three units here and a reduction over the second-two units at 54%, giving the overall reduction of 70%. Tests were not made across the second or third units separately, however if one assumed the same reduction of B. O. D. across each one, the individual B. O. D. reductions would be 32%. This suggests a B. O. D. reduction of 30 to 35% for each of the one day detention units operated in series and for purposes of comparing the Stony Plain ponds to those listed in Table 30A, the B. O. D. reduction would be 33%.

There appears to be a definite relationship between the detention time in days and the percentage of B. O. D. removals in these Short Detention Ponds, with the exception of the Two Hills installation. This exception is attributed to the unusual depth of the pond which was 18 feet compared to depths of 4 to 6 feet in the others. The other installations would indicate an optimum detention time of about five days, at which a B. O. D. reduction of some fifty percent might be expected. The B. O. D. loading on this basis would be 990 lbs/acre/day or 198 lbs/acre ft. /day for a sewage flow of 100,000 gallons per day at a B. O. D. of 350 p. p. m. The upper limit for B. O. D. loading is considerably higher than this as the first Stony Plain pond was operating quite satisfactorily at a loading of 4920 lbs/acre/day or 984 lbs/acre ft. /day. Also, the biological processes involved here are basically anaerobic and therefore, the operation might be compared to that in a sludge digestion tank. The B. O. D. loading on the digestion tank, assuming 30% of 0.26 lbs B. O. D. per person per day, a tank capacity of 3 cu. ft. per person and a holding time of six months, would be 5,900 lbs/acre foot/day or six times that in the Stony Plain first pond. Practical considerations would seem to rule out loadings of greater than about 5,000 lbs. B. O. D./acre/day as the build up of sludge would be such that cleaning would be required more than once a year to avoid serious flow channelling and exposed sludge solids.

With respect to other aspects of the operation of the short detention ponds, the following observations were made:

(a) Odor Nuisance: odors were very light and not noticeable more than a hundred feet away when the pond was working properly as at Stony Plain. Some odor problem existed at three ponds and this was attributed to a different reason in each case. One had a detention time of 11 days, which is considered too long, another received some cheese plant waste and the third was treating sewage with a sulfate content of 700 p. p. m.

(b) Ammonia Reduction: no significant change from that of the raw sewage.

(c) Phosphate Reduction: very little.

(d) Coliform Bacteria Removal: Some, but not of practical significance.

The Long Detention Ponds which were studied all received raw sewage and had Detention Times in the range of 100 to 300 days. In operation they were all similar during the summer time and the following general observations were found to be indicative of good operation:

(a) pH - in the range of 8 to 10.

(b) Color - Green - due to algae content.

(c) Odor - no detectable odor in the area surrounding the ponds.

The treatment efficiency of the ponds was gauged mainly by the reduction of B. O. D., ammonia and of coliforms. The single cell ponds gave B. O. D. reductions of about 80%, and reduction of coliforms and ammonia of about 90%. The Drayton Valley pond is operated as a series of three units and gave B. O. D. reduction of about 90%, ammonia reduction of some 90% and almost complete removal of the coliform bacteria. In addition the effluent from the third pond was very clear and had a low phosphate and detergent content.

The B. O. D. loading of the two single unit ponds was about 20 lbs/acre/day while in the first unit of the three unit pond it was about 80 lbs/acre/day. While this higher loading did not seem to upset the operation unduly, it was noted that the B.O.D. reduction was only 73%. This and the possible adverse effect of slightly higher than normal amounts of industrial wastes in some communities, indicated to us that a maximum design loading of 60 lbs of BOD/acre/day was desirable.

Winter time operation of the Long Detention Ponds is markedly inferior to that realized in the summer. The reduced temperatures of the liquid, 32 deg. F., as compared to summer temperatures of 50 to 70 degrees, no doubt has some effect but this may not be significant in view of the long detention times involved. The most important factor is felt to be the presence of the ice cover and a light insulating layer of snow - which reduces the oxygen producing capabilities of the algae to the point where there is a deficiency of oxygen in the pond liquid. Subsequently anaerobic decomposition processes start to predominate and in a manner which generates odorous materials. Our observations of the sulfate content of the liquid during the winter showed a definite reduction in only two of the four studied and an odor of hydrogen sulfide was noted only in those two. These odors are not noticed in the surrounding areas until the ice starts to melt in the spring, however they continue for a period of from 2 to 6 weeks each spring and this makes it desirable to locate the ponds at least a half mile from urban areas and one quarter of a mile from individual residences.

There has been no particular effort made by any municipality to minimize the spring time odors by chemical treatment up to this time, possibly because there have been few complaints due to the pond locations. The Department of Health has done some limited tests on one quart samples in the lab and also placed in the berms of the pond but the results were not conclusive. The use of the short detention ponds preceding the long detention ponds may give an improvement by reducing the carbonaceous organic loading of the ponds. At this time there is only one pond system of this type in operation and the limited observations indicate that there is an appreciable improvement but some odors are generated in the latter part of the winter. Similarly it was noted at Drayton Valley that the odors disappeared from the third unit in a 2 week period while it took four weeks for the odors to disappear from the first unit.

The cost of constructing sewage ponds in Alberta generally range from $800.00 to $1200.00 per acre, exclusive of land costs. Agricultural land for the ponds ranges from $150. to $300. per acre for the small to medium sized communities; for cities of 50,000 population and higher, the land costs would be up to $1,000. per acre. The contract for a new pond system for a community of 2,000 people was awarded this spring at a price of $30,800.00. The size of this pond was 31 acres including a strip of 100 feet outside the toe of the berms. This is a cost of $994.00 per acre and it is estimated that the land cost would be $200.00 per acre giving a total cost of $1200.00 per acre or a sum total cost of $37,200.00 to the town. The per capita cost for the present 2,000 population is $18.60 and for the design population of 3,000 it is $12.40 per capita. Some of the design data for this pond are as follows:

Present Sewage Flow - 50 g.pc.d. for 2000 - 100,000 g.p.d.

Short Detention Ponds - 4 @ 4.5 days detention each.
- depth - 10 ft.
- inside berm slope 3:1
- outside " " 2:1
- Connecting piping will permit use of 4 or 3 of the units in series.

Long Detention Ponds - 2 - 1 @ 33 days detention with an operating depth of 6 feet.
- 1 @ 296 days detention with an operating depth of 7.5 feet.
- Berm slopes of 4:1 and 3:1 inside and outside respectively.

SUMMARY

Sewage ponds are used extensively in Alberta and are effective in the treatment of sewage and also as storage facilities to enable controlled release of the sewage. Short Detention ponds with a detention time of one to five days are effective in so far as B. O. D. removal is concerned and operate efficiently in both winter and summer seasons. These are increasingly effective when used as three or four separate units operating in series.

Long Detention ponds having a B. O. D. loading of not more than 60 lbs. of B. O. D. / acre/day are effective during the summer season particularly if constructed to operate in a series of two or more units. There would appear to be very definite advantages in having the short Detention Ponds precede the Long Detention Ponds. With where Long Detention Ponds in series, or two Long Detention Ponds in series, preceded by the Short Detention Ponds almost 100% treatment of the sewage would be expected during the summer season.

Winter time operation of the Long Detention Ponds is not as effective and some odors are experienced in the spring for 2 to 6 weeks after the ice starts to melt. These odors make it desirable to locate the ponds one half mile from urban areas and one quarter mile from individual residences but has not been a serious problem.

It is expected that sewage ponds will continue to be widely used by Alberta communities, particularly those with populations of less than 10, 000 to 20, 000 people. The Short Detention Ponds may prove to be useful and economic for even the larger cities.

Local health hazards have not been noted. The growth of flies or mosquitoes has not been a problem and special control measures have not been necessary except to construct in a manner which avoids shallow areas and to keep grass and weeds under control during operation.

The use of sewage pond water for irrigation or other purposes has been very limited to this time. One community of 3, 000 people which is disposing of the accumulated water by irrigating alfalfa fields is the only one making definite use of the water.

ACKNOWLEDGEMENTS

The kind permission of the Honorable J. Donovan Ross, M. D., Minister of Health, Government of Alberta, to prepare and present this paper is gratefully acknowledged. The financial assistance of the Government of Canada, Department of National Health and Welfare, for the research study of the Sewage Ponds is also gratefully acknowledged.

SEWAGE LAGOONS AND MOSQUITO PROBLEMS

by

Leslie D. Beadle and John A. Rowe[*]

The question of the mosquito breeding propensities of sewage lagoons has been raised frequently. In at least 10 States, either State or Federal personnel have made observations on this problem.

Interest in these installations has been motivated by the mosquito annoyance problem and the generalized encephalitis threat in the western half of the country. It is well established that mosquito vectors of St. Louis encephalitis and western encephalitis are produced in large numbers in almost any accumulation of water, but especially in waters with high organic content. Sewage lagoons are of particular concern since they are usually located within mosquito flight range of a town.

The purpose of this paper is to bring together a summary of existing data on mosquito production in sewage lagoons. Our definition of a sewage lagoon is a man-made structure of controlled size and shape that is designed to receive raw or settled domestic sewage.

There have been no extensive investigations on this problem. Specific observations have been published from Texas -- Eads (1); Eads and Menzies (2); Harmston *et al*. (3); the Dakotas -- Beadle and Harmston (4); and Nebraska -- Rapp (5). Unpublished data are available from Arizona, Georgia, Mississippi, Missouri, Oklahoma, and Tennessee. Experiences pertaining to mosquito control on an oxidation pond in California have been described by Sampson (6).

Table 31 summarizes entomological data for sewage lagoons in 10 States located in 3 geographical regions. The predominant species found in the lagoons were *Culex tarsalis* in the Midwest and *C. tarsalis* and *Culex pipiens* (*quinquefasciatus*) in the Southwest. Up to the present, only light production of mosquitoes has been observed in southeastern installations.

Additional species of mosquitoes taken in sparse numbers from the sewage lagoons include the following: *Aedes campestris* (North Dakota), *Aedes dorsalis* (North Dakota and South Dakota), *Aedes vexans* (Arizona and Nebraska), *Anopheles quadrimaculatus* (Missouri and Tennessee), *Culex erraticus* (Mississippi and Tennessee), *Culex restuans* (Nebraska and North Dakota), *Culex salinarius* (Georgia and Texas) *Culex thriambus* (Texas), *Culiseta inornata* (Nebraska and Oklahoma), and *Psorophora confinnis* (Arizona).

The intensity of mosquito production in the lagoons surveyed has varied directly with the amount of weed growth. Those shallow ponds that have contained abundant emergent vegetation invariably produce tremendous numbers. Other ponds where such vegetation is marginal may produce large numbers along the peripheral area. Conversely, ponds free from vegetation have presented no mosquito problem. There does not appear to be a correlation between the oxidizing efficiency of the pond and mosquito production.

The "weedy" condition in sewage ponds may be related to several factors, one of the most important being faulty filling of the pond. It has been observed in a number of instances that filling difficulties and the concomitant shallow weedy conditions are related to the porous nature of the soil and the lack of attention to sealing of the pond. It also has been observed that many weedy situations are due to over design. In many of these cases, ineffective attempts have been made to establish a functioning pond by building cells in the bottom. We have the feeling that many of the earlier ponds were

---

[*] Communicable Disease Center, Public Health Service, U. S. Department of Health, Education and Welfare, Atlanta, Georgia.

TABLE 31

SUMMARY OF ENTOMOLOGICAL INSPECTIONS AT SEWAGE LAGOONS IN 10 STATES

State	No. of Ponds Sampled	Ponds Producing Mosquitoes		Ponds Producing	
		Number	Percent	*Culex tarsalis*	*Culex pipiens**
Midwest					
Missouri	9	4	44	3	3
Nebraska	30	15	50	10	2
North Dakota	12	9	75	9	0
South Dakota	15	10	67	10	0
Southwest					
Arizona	18	10	56	7	8(*C.q.*)
Oklahoma	35	6	17	2	5(*C.q.*)
Texas	37	23	62	14	17(*C.q.*)
Southeast					
Georgia	3	1	33	0	0
Mississippi	9	1	11	0	0
Tennessee	3	2	67	1	0

*The *Culex pipiens* complex includes Culex quinquefasciatus (*C.q.*).

too large for the communities that they served.

In certain communities, it has been noted that weed problems in the lagoons have been minimized because the ponds were filled with water immediately following construction; whereas in other communities that have not utilized the water filling method but have utilized only sewage flows, the time required to fill the lagoons has been much longer and weed growth has been a problem.

Another problem related to weed control and to the proper management of the pond is the lack of outlet structures that permit complete water level control.

Inadequate lagoon maintenance -- such as lack of care by the operator of the lagoon -- is a frequent cause of weed problems in the lagoon proper or on the banks.

Suggestions for Minimizing Mosquito Breeding in Sewage Lagoons

Design and construction features

1. The proper size of the lagoon should be determined carefully. It should not be too large for the population served. Provision for multiple lagoons is an excellent means of allowing for expansion.
2. The lagoon should be constructed so as to hold water. Artificial sealing with chemicals, clay, bentonite, or plastic or asphalt membranes should be used if necessary.
3. Complete water level control and drainage structures should be built into the pond. Such structures facilitate the control of marginal vegetation by the use of water level management (draw-

down) coupled with soil sterilants. Lowering the water level temporarily also may be used to control mosquito larvae.

4. The dikes should be of sufficient width (generally 8 feet) to permit access of maintenance machinery such as seed drills, mowers, and larviciding or herbiciding equipment.

5. The inner bankment slopes should be relatively steep -- e.g., 3 or 4 feet horizontal to 1 vertical.

6. The depth should be as great as possible for maximum waste treatment. Depths of over 25 inches will discourage the development of cattail and other emergent plants (7).

7. The lagoon bottom should be cleared of vegetation prior to filling, and it should be as level as possible.

8. The lagoon should have a uniform shape with the inlet near the center of the pond.

9. The lagoon should be readily accessible. A roadway to the lagoon will encourage frequent inspection and facilitate movement of maintenance equipment.

10. The lagoon embankments should be planted with a suitable species of grass, such as brome. Care should be taken, however, to avoid species such as reed canary grass, which may invade water. Fertilization of the dikes will aid in the development of grasses.

Operational and maintenance features

1. If water is available, immediate filling of the lagoon to operational level will discourage the growth of vegetation.

2. All lagoons should receive regular and frequent observation and maintenance. Control of vegetation and mosquitoes should be a regular part of lagoon maintenance.

3. Undesirable vegetative growth in the lagoon proper or on the dikes should be eliminated periodically by mowing or by use of suitable herbicides. If the weeds are mowed, care should be taken to see that the cut-off plants do not float in the lagoon and provide harborage for mosquitoes. The planting of water-loving plants such as willows or poplars should be discouraged.

4. Larvicidal measures should be used in the event that significant mosquito production takes place in the lagoon. The following materials have been used effectively: diesel oil (thin layer): 1 or 2% oil solution of DDT; BHC dust (3% gamma isomer); or 2% malathion emulsion.

Summary and Conclusions

Present evidence indicates that many sewage lagoons in the Midwest and Southwest are producing mosquitoes. In many of these, the numbers of mosquitoes produced are of real significance. In general, mosquito production is directly proportional to the extent of vegetation (weed growth) in the lagoons.

Because of the usual proximity of lagoons to small communities and to residential areas in metropolitan centers, mosquitoes produced cause considerable annoyance. More important than their annoyance is the fact that the major species found -- *Culex tarsalis* and the *Culex pipiens* complex -- are primary vectors of encephalitis. In order to protect the public health, large populations of these species should not be permitted to occur in areas close to populated areas.

Certain design and operating features of lagoons are important to mosquito prevention. Basically, they are features designed to prevent or minimize weed growth.

There can be no doubt that sewage lagoons are gaining in popularity throughout the country, and they should continue to be developed. It is hoped that health agencies and other groups concerned with the construction and use of these ponds and particularly those groups who are charged with their care will proceed with the development and use of ponds in such a manner that production of mosquito vectors of encephalitis will be minimized.

We would urge health agencies in various geographical areas to continue making observations on lagoons and to report the information so that everyone will benefit by the findings.

Acknowledgment

The writers are grateful to the following persons who provided us with unpublished data from their respective States: G. Allen Mail and George R. Hayes, Jr. (Arizona); Clyde F. Fehn (Georgia): LeRoy K. Rachels and Reuel H. Waldrop (Oklahoma): James L. Church, Jr. (Tennessee): and William F. Rapp, Jr. (Nebraska).

References

1. Eads, R. B.: Vectors of encephalitis. Texas Health Bull. 9:16-17, June 1956.
2. Eads, R. B., and Menzies, G. C.: Texas mosquito problems from a species standpoint. Mosquito News 16: 188-189, September 1956.
3. Harmston, F. C., Shultz, G. R., Eads, R. B., and Menzies, G. C.: Mosquitoes and encephalitis in the irrigated High Plains of Texas. Public Health Rep. 71:759-766, August 1956.
4. Beadle, L. D., and Harmston, F. C.: Mosquitoes in sewage stabilization ponds in the Dakotas. Mosquito News 18:293-296, December 1958.
5. Rapp, W. F., Jr.: Sewage lagoon maintenance. Water Pollution J. 32: 660-662, June 1960.
6. Sampson, E. O.: A double duty oxidation pond. Sewage & Industr. Wastes 27:1414, December 1955.
7. Steenis, J. H., Smith, L. S., and Cofer, H. P.: Studies on cattail management in the Northeast. Trans. NE Wildlife Conf. 1:149-155, 1958 (1959).

LAGOONS FOR HOG FEEDING FLOORS

Ralph L. Ricketts*

Confinement feeding of hogs in Missouri is gaining in popularity. Probably the biggest single job connected with this feeding is disposal of manure. Our hog feeders are searching for an answer to this problem. One solution that offers definite possibilities is the use of lagoons.

A survey made in Missouri indicates that about 50 lagoons were in use in 1959. One hundred more are planned for 1960. The size of those constructed range from less than 10 square feet to 30 square feet per hog capacity of the feed floor. The average size is about 15 square feet per head. Most of the farmers contacted were satisfied with the performance of the lagoons. Thirteen said they were highly pleased and only two said they were not satisfied with the units. About one-half were built adjacent to the feed floor and the remainder at a distance from the floor with a tile used to carry the liquid and manure to the lagoon. About one-third have been in use more than a year and the remainder in use less than one year.

A study of the results of this survey plus conversation with various farmers using lagoons allows us to develop some tenative suggestions. We are not, however, either encouraging or discouraging them at this time. These suggestions are made to give assistance to those giving thought to the installation of one. It is emphasized that lagoons are experimental and that further study and research is needed concerning their design and use.

SIZE: - Minimum of 15 square feet surface area per head capacity of feeding floor. This will be almost as large as the feed floor.

DEPTH: - Minimum of 3 feet.

LOCATION: - Most convenient from standpoint of use is to place adjacent to the feed floor as shown in Sketch 1. Floor can be easily cleaned by hosing or scraping directly into lagoon. Where conditions are such that adjacent location is not possible, lagoon may be placed at a distance from the feed floor and the manure carried to it by a tile as shown in Sketch 2. However, more trouble is experienced getting manure to the lagoon when the tile is used. Usual way is to build a gutter along the south side of the feed floor, sloping it to the center where the tile is located. This tile carries the manure to the lagoon. Considerable water is necessary to avoid tile stoppage. Some feeders plug the tile opening until considerable solids and liquids have accumulated in the gutter. The solids seem to move through the line better in larger quantities. The outlet of the tile should be about 24" above the liquid surface in the lagoon and about in the center of it. Tile slop should be about 1/4" per foot and minimum diameter 6". Eight inch diameter would be more desirable.

CLEANOUT: - Apparently lagoons do not have to be cleaned often. Some have been in use more than a year and have never been cleaned. Cleaning can probably best be done by use of liquid manure pump. Another method is to drain lagoon, then remove solids with scraper after they have dried.

WATER: - Lagoons should be kept filled with water. Where soil conditions are right, water from the feed floor plus rain water falling on the feed floor and into the lagoon is sufficient to keep them filled. No surface water should be allowed to enter them except perhaps during the initial filling period.

ODORS: - Some odors should be expected. While these are called lagoons, they probably function more nearly like large open topped septic tanks. More study is needed on this point, but if the water basin in which hog wastes are placed operated as a true lagoon, only oxygen would be released and there would be no odor. However, if we use the same standards for designing lagoons for hog wastes as for sewage from tourist courts, trailer courts, schools, etc., a lagoon 1 to 2 acres in size would be required for 100 hogs. This size would be impractical in most instances. There are odors from the feed floor and some additional from the lagoon are not objectional provided they do not become excessive. Lagoons and hog feeding floors should be 500 feet from the dwelling and preferably in a direction other than the prevailing winds.

---

*Extension Agricultural Engineer, University of Missouri, Columbia, Missouri.

The hog feeding arrangement shown in the photograph is one of the best planned units in Missouri. It is on the Bob Tackett farm near Warrensburg, Missouri.

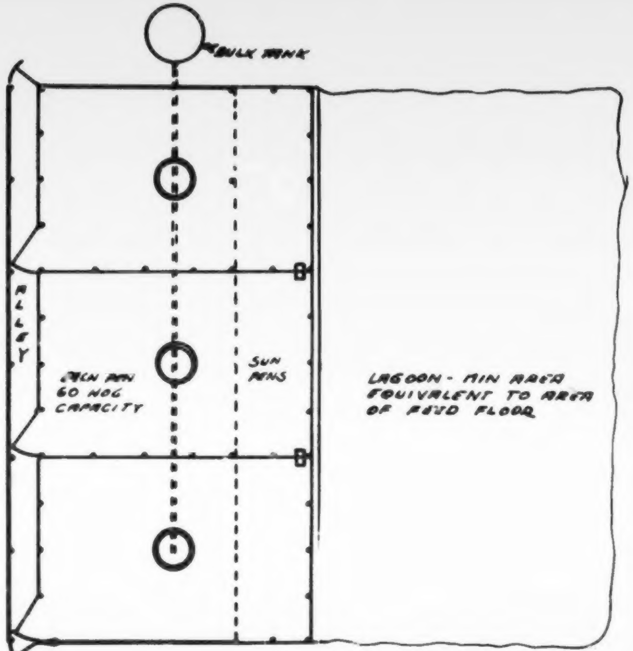
The building is 30 feet wide. A 10-foot wide alley is provided along the north side of the building interior for access. Size of the feeding floor is 30 feet by 110 feet. Twenty feet of the feed floor is under roof and the remaining 10-foot width is sun pens along the south side of the building. The inexpensive shelter gives protection from wind and snow during the winter months and provides effective shade during summer months. Fog spray nozzles are also used for summer time cooling. Automatic waterers are provided in each pen. Floor slopes to the front or to the south 1/2" per foot except in the bedding area along the back or north side of the pens where the slope is reduced to 1/8" per foot.

The lagoon is 21 feet by 110 feet. Usually, manure is pushed into it with a snow shovel. Sometimes the floor is cleaned by hosing.

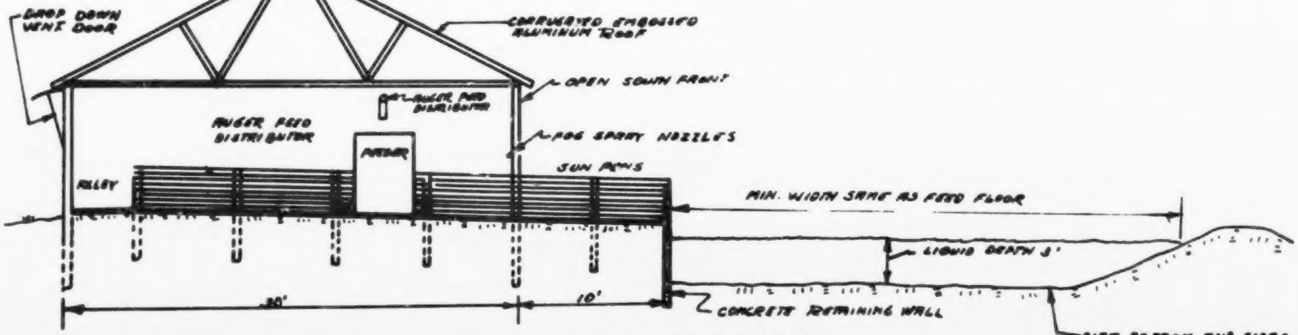
Advantages of the unit may be pointed out as follows:

1. Original cost is kept low.
2. Labor problem of feeding and care of hogs is kept to minimum.
3. Fly problem is reduced.
4. There is no mosquito problem.

About the only disadvantage is that odors are excessive at times during days of high relative humidity.

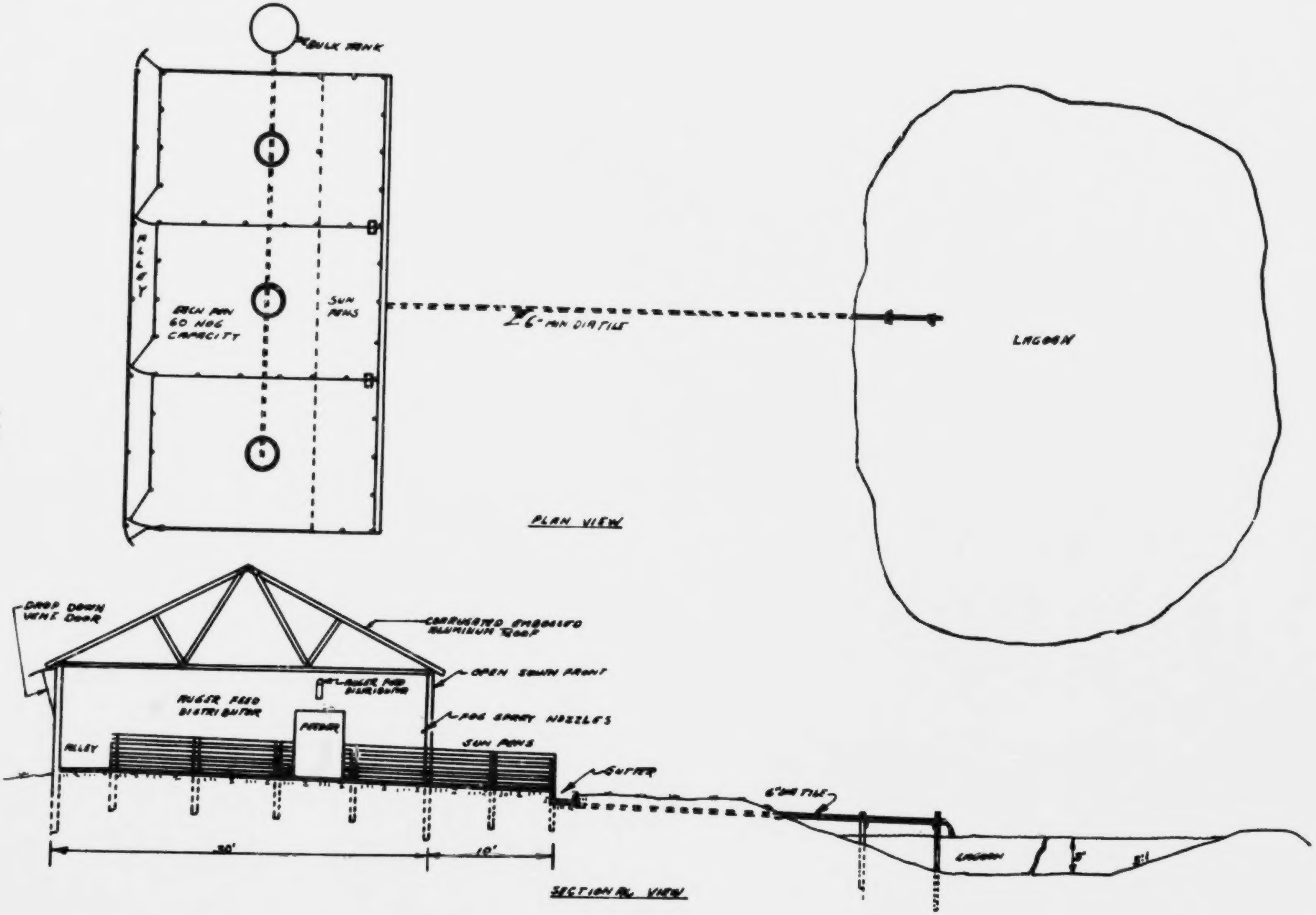

BULK TANK
ALLEY
EACH PEN 60 HOG CAPACITY
SUN PENS
LAGOON - MIN AREA EQUIVALENT TO AREA OF FEED FLOOR

PLAN VIEW


DROP DOWN VENT DOOR
CORRUGATED EMBOSSED ALUMINUM ROOF
OPEN SOUTH FRONT
AUGER FEED DISTRIBUTOR
AUGER FEED DISTRIBUTOR
FEEDER
FOG SPRAY NOZZLES
SUN PENS
ALLEY
MIN. WIDTH SAME AS FEED FLOOR
LIQUID DEPTH 3'
30'
10'
CONCRETE RETAINING WALL
DIRT BOTTOM AND SIDES

SECTIONAL VIEW

SKETCH NO. 1


BULK TANK
ALLEY
EACH PEN 60 HOG CAPACITY
SUN PENS
6" MIN DIA TILE
LAGOON
PLAN VIEW
DROP DOWN VENT DOOR
CORRUGATED EMBOSSED ALUMINUM ROOF
OPEN SOUTH FRONT
AUGER FEED DISTRIBUTOR
AUGER FEED DISTRIBUTOR
FEEDER
FOG SPRAY NOZZLES
SUN PENS
ALLEY
GUTTER
30'
10'
6" DIA TILE
LAGOON
5'
3:1
SECTIONAL VIEW

SKETCH NO.2

REPORT ON NORTH DAKOTA USE OF SEWAGE STABILIZATION LAGOONS*

by

W. VanHeuvelen*

This year completes a ten-year period in which lagoons have been used in North Dakota at an ever-increasing rate and extensively adopted as the method of municipal sewage treatment. On July 1, 1950, there were three sewage lagoons operating in our state, while this year on July 1, 1960, we find 113 such installations. As a point of interest, on July 1, 1950, there were 76 primary sewage treatment plants--principally imhoff tanks--while today in North Dakota you will find 37, a decrease of 39. Lagoons have replaced 50% of the primary treatment plants in our state. The same thing is true of secondary plants. In 1950 there were 12 secondary treatment plants, while today there are 7, with 5 of these being replaced by lagoons. 1960 will see the replacement of another secondary plant, which has been used only ten years, by a lagoon.

Lagoons have encouraged the development of a large number of new sewage collection systems in our state. In 1950, there were a total of 107 sewage collection systems in North Dakota. In 1960. there are 173 sewage systems, 65% using lagoons. All 66 of the new systems were developed with this type of treatment. Lagoons have not only been used by the small communities in North Dakota, but have become the type of treatment used by our major cities. Of the twelve major cities in the state, six are presently using sewage lagoons. These include Williston, Dickinson, Devils Lake, Grafton, Jamestown, and Wahpeton. These communities range in population from 5 to 12 thousand. Of the other six major communities, Minot (30, 277), Grand Forks (34, 256), and Valley City (7, 758) will start lagoon construction sometime during the present calendar year. Lagoons are being planned for the cities of Mandan and Bismarck. This leaves one major community, Fargo, which is presently expanding their secondary treatment plant. We except in the very near future to find eleven of the twelve major communities in North Dakota using lagoons as a treatment method.

The basic design of lagoons now being built in North Dakota is about the same as that used for the installation built at Maddock in 1949. Design loading is generally 20 pounds of B.O.D. per acre per day with a maximum limit of 40 pounds B.O.D. per acre per day. Due to wide variations in rainfall and climatic conditions across our state, there is some difference in design between the eastern and western portions. In the western part of our state, rainfall is less and the soil is generally lighter. Therefore, to secure proper hydraulic loading, the B.O.D. loading will often be in the neighborhood of thirty to thirty-five pounds per acre per day. We are actively encouraging the development of two units, which can be operated in either parallel or series.

We are still recommending location of units as far away from existing and future residential and commercial developments as is reasonable and feasible. This distance will vary with local conditions. Lagoons should be located adjacent to a water course. Recommended dikes are constructed much the same as ten years ago with an 8 foot height, 3 feet of free board, well compacted, and a width of 8 to 10 feet. Dike structures vary in width and slope with the size of the installation. North Dakota still recommends a 5 foot liquid depth with a control structure for lagoon operation at any selected depth. The lagoon bottom should be made as level as possible. Influent lines are placed near the center of the lagoon or in large installations far enough from any bank to insure circulation. Interconnecting piping or structures vary widely but all should offer flexible depth control. Do not build in complicated features -- stick to design features.

---

*Executive Officer, State Department of Health.

One of the major advantages of lagoons in North Dakota is the fact that they can be so designed as to discharge effluents during periods when there is sufficient stream flow to provide dilution water. Most North Dakota streams are intermittent with high flows in early spring, low summer flows, and often zero flows during the winter months. Our lagoons are designed to provide winter storage of about 120 days. Winter is a critical period for streams in our state and if all sewage can be held within the lagoon, real water pollution abatement is being achieved. We are encouraging operational practices, which include partial draining of the lagoon prior to winter freeze-up to make room for winter sewage flows. The effluent in the fall months is highly stabilized and adds a minimum of waste load to the water course. We also encourage a discharge from the lagoon during the early spring months when there is adequate dilution water in the receiving stream. If the level of the lagoon can be lowered during the spring break-up period, the transition period is more rapid.

Lagoons in North Dakota operate, generally, with no problems during the summer, fall, and winter months. There is a spring transition period when odors may develop for a period, depending upon several factors. The length of this transition period is dependent upon depth of sewage in the stabilization lagoon, the organic load, the period of time between freezing and above-freezing temperatures, the amount of sunshine, the type of industrial wastes that the lagoon receives, the quality of the municipal water supply and perhaps some unknown factors. The duration of the transition period in a lagoon may vary from a few days to an extended period. During the past ten years we have observed that lagoons which have been loaded to design standards present minor transition problems.

Where there have been transition problems, we have felt that these problems would have existed during most of the year were this particular waste being treated in a conventional type of sewage treatment plant with the average type of operation which is found in our state. Also, I might point out that a lagoon is always subjected to an FBI type of investigation in regards to odor, while those visiting conventional plants know that there will be odor before they reach the plant; therefore, they do not make nearly as intense observations of these odor problems.

We are having some excellent results with the treatment of industrial wastes in stabilization lagoons and also some problems. A majority of our lagoons treat domestic sewage combined with a small industrial load. One of our earliest problem lagoons developed severe odors during an extended transition period due to the fact that large quantities of milk waste, buttermilk, and slaughter plant wastes were being discharged to the lagoon. The strength of these wastes was about four times that of the domestic sewage received by this treatment device. With elimination of the buttermilk and some in-plant separations of slaughter plant wastes and decrease waste loads, this problem has been considerably alleviated, so that the transition period on this installation is now very short. One of our outstanding industrial installations is located at Mandan, North Dakota, at the Standard Oil Refinery. This nine-acre lagoon services a 50,000 barrel a day refinery. The wastes are first treated in an API separator and then discharged to the lagoon. The Standard Oil Company has taken a real interest in the operation of this lagoon and has carried on a considerable amount of experimental work. Water temperatures are controlled, aeration is provided through the use of Kesserling Brushes, and a floating skimmer removes any oil separated in the lagoon before it is discharged to the stream. This lagoon provides the refinery with considerable oil and phenol removal and permits the refinery to discharge the well-treated effluent which creates no problem in a stream with an average summer and winter flow of about 6 CFS.

During the last two years, we have had a rapidly growing potato products processing industry developing in North Dakota. This includes a potato starch plant and several potato flake plants. The wastes from these potato processing plants have varied from 860 to 3,000 mg per liter, 5 day B.O.D. Suspended solids have varied from 1,400 mg per liter to 4,000 mg per liter. The flake plants have developed a waste strength which amounts to about 350 population equivalents per ton of potatoes processed, with these plants varying in size from about 50 to 100 tons per day. In all cases where these plants have discharged their effluent to a lagoon, the major portion of the waste strength of the lagoon came from the potato processing plant. Our department has required preliminary treatment of these wastes before discharge to a lagoon and found that by two hours' settling, about 50% of the waste strength can be removed. These rapidly developing industries have loaded some lagoons as high as 150 pounds of B.O.D. per acre per day during the last year. Operation has been satisfactory during the summer, fall, and winter months. However, very serious odor problems did develop this last spring and persisted for several months. Grafton, North Dakota, a community of a little over 5,000, has a potato flake plant processing 72 tons of potatoes a day and a potato starch plant processing about 360 tons per day. The loading on this lagoon was in the neighborhood of 150 pounds of B.O.D. per acre per day. During the past two months of open weather with considerable sunshine, we have found a decrease in the B.O.D. strength of the lagoon contents, a film of algae developing, and the treatment process taking place. We trust that if proper pre-treatment of waste is accomplished that a properly loaded and designed lagoon will treat these potato effluents.

We also find the transition period is extended considerably if the lagoon is served by a municipal water supply which contains a large amount of sulfates. At the city of Devils Lake, which has a 95 acre lagoon, the municipal water supply has 1,100 parts per million sulfate. A mild odor was reported at this installation in the latter part of June this year. This community is soon changing their water supply, and therefore will eliminate this problem, but certainly the amount of sulfates in the municipal water supply should be considered in the development of a stabilization lagoon. I should not intimate that overloading is the only problem. Both organic and hydraulic underloading can also produce undesirable operations. If soil conditions are not adequate or lagoon area is too large, proper liquid depths will not be maintained and poor operation conditions will develop.

May I sum up this report from North Dakota in saying that after ten years of experience and 113 stabilization lagoons, we are sure that this is now the accepted method of sewage treatment in our state. There have been problems, and there will continue to be some problems -- mostly related to the overloading or underloading of the installation, thereby developing odor problems during the spring transition period. If a lagoon is properly designed and properly operated, it will provide a community with a trouble-free, economical, and satisfactory treatment installation.

RAW SEWAGE LAGOONS IN MONTANA

by C. W. Brinck *

Raw sewage lagoons have revolutionized sewage treatment in Montana. In 1952, upon the urging of the U. S. Public Health Service, Missouri Basin Office and the kind invitation of the State of North Dakota, Montana was included with other Missouri Basin States in a trip to study lagoon installations throughout North Dakota. As a result of this beginning, Montana had 44 standard sewage lagoons in operation and 11 under construction, as of July 1, 1960. We also have a lagoon that was built in 1911, but not recognized as a lagoon. This lagoon provides sewage treatment for a community of 2,730 people and consists of four ponds, three of which are in operation and a fourth one which is drying and awaiting being cleaned. The ponds are operated in series. Each year, the pond which has received the primary sewage is taken out of service after being in use for a full year and the sludge is permitted to dry and is bull-dozed from the pond. The following year, this pond becomes the third in series, the third pond becomes the second pond in the series and the second pond becomes the first in the series. This facility has performed satisfactorily without odors for forty-nine years. The sewage is very weak because of large quantities of infiltration water. This weak sewage was long believed by State Board of Health representatives to be the reason for no odors being created at this sewage pond.

Lagoons have been very successful in Montana since the first one designed as a sewage lagoon was constructed and placed in operation in 1953. Typical comments concerning sewage lagoons are along this line: "Most logical and economical way to meet our sewage disposal problem." "Everything about it is excellent and maintenance problems are practically zero." "We recommend it for any town or city." "No upkeep or maintenance problems since construction other than riprapping banks." "Very well pleased with operation and costs - No operational problems so far." "Very cheap." "It is very satisfactory."

These few comments represent the feeling of many of our communities in the State that have sewage lagoons. There are still some communities that do not have lagoons and look upon the sewage lagoon with some skepticism. The costs shown in the accompanying table reflect land and lagoon costs only. These costs vary with the cost of the land. Also, the contractors costs vary for dirt moving, the type of soil and the way the earth must be moved to provide a relatively level bottom for the pond.

Seventeen of the 44 lagoons in Montana are of the two-cell type. Recommendations are for two-cell structures because of the greater flexibility that is provided when the two lagoons are so designed that they can be operated either in parallel or in series, depending upon the load. We particularly recommend the two-cell lagoon for a community that is just being sewered for the first time since it frequently requires considerable time to get all of the dwellings in the community to connect to the sewer. This is particularly true these days because the communities that had sewers a number of years ago usually were the communities where a septic tank would not operate satisfactorily due to the tight soil and those that have remained unsewered have been able to make septic tanks and cesspools operate because of the fairly coarse gravelly soil.

Many of the lagoons in Montana are provided with a sewage line which discharges above the water surface. In only one instance has it been reported that the pilings were raised by ice in the winter. Many Montana lagoons will have as much as two feet of ice a short distance away from the point where the liquid enters the lagoon. This point is open because of the heat in the sewage. Many persons have expressed concern because of the conditions developed by the cold weather. Some of our lagoons are located in areas where the thermometer will drop to a temperature of minus 50 degrees F., almost every winter. Yet

---

*Director, Division of Environmental Sanitation. Montana State Board of Health the lagoons operate satisfactorily. Because of ice conditions, Montana feels that it is absolutely necessary to design a lagoon to provide a five feet liquid depth. This may be reduced to three feet in the summer, but with two feet of ice to contend with in some localities, it is necessary to have some place for the liquid under the ice. Therefore, practically all lagoons that are going in are five feet deep.

One lagoon in Montana was established to handle the wastes from a 23,000 barrel per day oil refinery. This oil refinery produces a waste which contains large quantities of phenol. The refinery instituted a program whereby as much water as possible was conserved and reused, discharging only that water which had a relatively high dissolved solids concentration. After passing through the oil separator, the waste water contains both oil and phenols, together with boiler blow-down wastes, it is discharged to a two-cell lagoon, operating in series. In this lagoon, biological activity reduces the phenol content to a point from approximately 100 pounds per day to less than 0.1 pounds per day. Needless to say, management, the down-stream users, and the State Board of Health are pleased with these results.

Two packing plants use lagoons for their waste disposal. The tendency here is for the plants to overload the lagoons, to permit too much blood and other material to escape in the waste water, thus overloading the lagoons and creating an odor condition. In one plant this is quite serious since there are neighbors nearby and there is no place for them to discharge their wastes. The plant was built in an area where there were no persons residing a few years ago. The area has now been subdivided and is heavily built up.

Lagoons have been considered for sewage treatment for some of the larger communities (up to 55,000 population) but, due to the excessive pumping costs or the excessive cost for available land, the general decision has been to use the mechanical type of treatment for these communites. We would not hesitate to approve the use of a sewage lagoon for these larger communities if the engineers decided that it was the answer to the problem in Montana.

Lagoons are inexpensive to construct, as compared with a mechanical plant; for operation, costs are practically nil as compared with a mechanical plant, and the degree of treatment is much higher than is ordinarily obtained with the customary mechanical primary or secondary plant. Therefore, on this basis, we have not hesitated to recommend sewage lagoons to our municipalities in Montana. We now find that many municipalities are convincing other municipalities on the suitability of this method of sewage treatment. That, together with the material that appears in the literature information from consulting engineers, the State Board of Health, and in the Readers Digest has been most helpful in changing a situation in Montana from one where, about eight years ago, we had about 20 acceptable sewage treatment plants in Montana, and today, we have 85 that are acceptable and have 9 communities with money that are proceeding with planning for construction. These are both mechanical and lagoons. We hope that within the next year we will have the sewage from the remaining 33 municipalities treated. Twenty-four have plants needing some improvement, 3 are of uncertain status, but the remaining 6 are making plans and several have already purchased land for lagoons. Montana, we hope, will within the next year, be in a state that will have no raw sewage being discharged into its streams.

TABLE 32

RAW SEWAGE LAGOONS IN MONTANA

DIVISION OF ENVIRONMENTAL SANITATION

MONTANA STATE BOARD OF HEALTH

Municipality	1950 Census Population	No. Sewer Connections	Year Placed in Operation	Lift Station Cost	Number Lagoons	Total Lagoon Surface Area Acres	Acre Land Purchased	Land Cost	Construction Cost	Cost/Capita for Lagoon	Distance between Lagoon & Bldgs.	Odors
Baker	1,772		1956		2	14						
Big Sandy	743		[illegible]		1	[illegible]		1,200	11,306	19	1/4 Mile	
Bl. Tinter	1,079		[illegible]		1	15	[illegible]	22,500	22,960	2[illegible]		
Boulder (State)	[illegible]		1954		2	12			13,250	[illegible]	1/4 Mile	Yes
Brady	24[illegible]	125	[illegible]		1	3		600	5,000	20	1,000 Ft.	Yes
Bridger	[illegible]	40	[illegible]		1	2	[illegible]	20	[illegible]	1[illegible]	2,000 Ft.	No
Busby	[illegible]	25	[illegible]		2	3					1,200 Ft.	No
[illegible]	41[illegible]		1956		1	3						
Chester	733		1956		1	4						Yes
Choteau	1,813	4[illegible]	[illegible]		1	[illegible]	[illegible]	4,[illegible]	26,4[illegible]	2[illegible]	2,[illegible] Ft.	Yes
Circle	75[illegible]		[illegible]	2,5[illegible]	2	2[illegible]		3,[illegible]	11,0[illegible]	2[illegible]		Yes
Conrad	1,865		[illegible]		2	2[illegible]						
Culbertson	[illegible]	2[illegible]	1958	12,6[illegible]	1	11	4[illegible]	1,7[illegible]	16,452	1[illegible]	1/4 Mile	No
Cut Bank	3,[illegible]		[illegible]	[illegible]	2	41	[illegible]	4[illegible],1[illegible]	3[illegible],425	2[illegible]		
Denton	[illegible]	1[illegible]	[illegible]		1	5	11	1,[illegible]00	[illegible],1[illegible]0	1[illegible]	[illegible],2[illegible] Ft.	No
Dillon	3,268		[illegible]		1	4[illegible]	[illegible]	11,[illegible]	23,7[illegible]	[illegible]		
Dodson	[illegible]		[illegible]	[illegible],[illegible]00	1	[illegible]	[illegible]	[illegible],[illegible]00	[illegible],4[illegible]	21		
East Helena	1,216	4[illegible]	[illegible]		2	14			42,[illegible]50	32	2,[illegible] Ft.	No
Fairfield	4[illegible]	1[illegible]	1955		1	1[illegible]			27,6[illegible]	[illegible]	2 Mile	[illegible]
Forsyth	1,906		1959		1	2[illegible]			22,[illegible]	[illegible]		
Geraldine	[illegible]	1[illegible]	[illegible]		1	[illegible]			[illegible]	2[illegible]		[illegible]
Harlowton	1,733	[illegible]	[illegible]		1	22	2[illegible]	1,9[illegible]	2[illegible]	1[illegible]	1/2 Mile	[illegible]
Hingham	2[illegible]	[illegible]	1956		1			150/Ac.	7,898	[illegible]	1/4 Mile	Yes
Hobson	2[illegible]	[illegible]	[illegible]		2	1		[illegible]	[illegible]	[illegible]	[illegible] Ft.	No
Jordan	[illegible]		1956		1	4						Yes
Lame Deer	[illegible]	[illegible]	[illegible]		1	2					1,[illegible] Ft.	No
Lodge Grass	[illegible]	1[illegible]	[illegible]		1	4		2,[illegible]			[illegible] Ft.	Yes
Malta	2,[illegible]	[illegible]	1958	12,500	2	1[illegible]	[illegible]	[illegible]	34,2[illegible]	1[illegible]	1,[illegible] Ft.	Yes
Melstone	2[illegible]		[illegible]		1	2.5						
Opheim	[illegible]	110	[illegible]		1	[illegible]			20,488	53	1,2[illegible] Ft.	No
Plentywood	1,862	[illegible]	[illegible]		2	[illegible]	8	1,0[illegible]	2[illegible]	1[illegible]	1/2 Mile	Yes
Plevna	2[illegible]	[illegible]	1954		2	2	18	1,[illegible]	7,378	[illegible]	1[illegible] Ft.	No
Richey	[illegible]	1[illegible]	[illegible]		2	[illegible]			15,952	2[illegible]	2,[illegible] Ft.	Yes
Roundup	2,856		1958	7,5[illegible]	1	2[illegible]			18,925	[illegible]		
Ryegate	[illegible]				2	[illegible]						
St. Ignatius	[illegible]	[illegible]	[illegible]		1	[illegible]		[illegible]/Ac.	1[illegible],000	2[illegible]	[illegible] Ft.	No
Sheridan	7[illegible]		[illegible]		1	[illegible]	10.[illegible]	1,[illegible]	2[illegible],7[illegible]	42		
Stevensville	7[illegible]2		[illegible]		1	1[illegible]	[illegible]	1,500	14,827	1[illegible]		
Townsend	1,316		[illegible]		1	1[illegible]	20	[illegible],000	1[illegible]	14		
Valier	71[illegible]		1960		1	11	1[illegible]	2,2[illegible]	2[illegible],2[illegible]	40		
West Glendive	1,[illegible]		1958	7,[illegible]	1	1[illegible]	[illegible]	[illegible]	14,42[illegible]	14		
White Sulphur Springs	1,025	2[illegible]	[illegible]		2	1[illegible]	[illegible]	[illegible]	[illegible],482	[illegible]	1,500 Ft.	No
Wolf Point	2,551		[illegible]	15,[illegible]	1	4[illegible]	[illegible]	[illegible],15[illegible]	2[illegible]	8		
Worden	225	11[illegible]	1956		1	[illegible]		1,[illegible]	[illegible],2[illegible]	2[illegible]	1/4 Mile	Yes

TABLE 32

RAW SEWAGE LAGOONS IN MONTANA

DIVISION OF ENVIRONMENTAL SANITATION

MONTANA STATE BOARD OF HEALTH

Municipality	Season when odors noted	Recurrent odors	Odor Intensity	Time odors Noted	Description of odors	Complaints	Cold Weather Problem	Overflow	Effluent used	Days Maintenance per year	Sulfates mg/l
Baker											
Big Sandy											1000
Big Timber											800-1000
Boulder (State)	Spring		Mild	Few days	Sewage	No	No	Yes	No	None	27
Brady	Spring	Yes	Strong	14 days	Sewage	Yes	No	Yes	Irrigation	10 days	35
[illegible]						No	No	Yes	No	1 day	155
[illegible]						No	No	No	No	4 days	1267
[illegible]											
Chester	Spring			1-14 days	[illegible]	Few					3
[illegible]	Spring	Yes	Slight	1-2 days	Stagnant	No	No	No		2-3 days	600-900
Circle	Spring			1-14 days	Sewage	Few					50
Conrad											[illegible]
Culbertson											[illegible]
Cut Bank						None	None	None		1/2 hr/day	285
Denton											53
[illegible]						No	No	No		40 days	[illegible]
[illegible]											[illegible]
East Helena											285
Fairfield						No	No	Yes	Irrigation	None	[illegible]
Forsyth						No	No	Yes	No	30 days	22
[illegible]											[illegible]
[illegible]						No	No	Yes	No	7 days	[illegible]
[illegible]						No	No	No	No	Very Little	[illegible]
[illegible]	Spring	Yes	Light	14-20 days		No	Yes	No	No		[illegible]
[illegible]						No	No	Yes	No		
[illegible]					Sewage						[illegible]
[illegible]	[illegible]	No	Mild	Constant				No	No	30 days	
Malta						Yes	No	Yes	No	7 days	[illegible]
[illegible]	Early Spring	[illegible] years	Strong	[illegible] days	Sewage	Yes		Yes	Not Yet	7 days	[illegible]
[illegible]											[illegible]
[illegible]						None	[illegible]	No		Practically None	
[illegible]	Spring	Yes	[illegible]	[illegible] days	[illegible]	Few	No	Yes	No	[illegible] days	[illegible]
[illegible]						No	No	No	No	7 days	[illegible]
[illegible]	Spring	Yes	Mild	1-14 days		Yes	Stratification [illegible]	No	No	2 days	[illegible]
[illegible]											[illegible]
[illegible]											[illegible]
[illegible]							No	Very Little	No	[illegible] days	
[illegible]											[illegible]
[illegible]											
[illegible]											[illegible]
*[illegible]											[illegible]
[illegible]											
*[illegible]						No	[illegible]	[illegible]	No	[illegible] days	[illegible]
*[illegible]	Spring	Yes	Strong	2 weeks	[illegible]	No	None	No		Very Few	[illegible]

SEWAGE STABILIZATION PONDS IN MINNESOTA

Harvey G. Rogers*

Sewage stabilization ponds have been used for the treatment of raw sewage and industrial waste from municipalities in Minnesota since 1955. As of May, 1960, there are twenty-one municipal projects for treatment of raw sewage and industrial wastes which have been completed or are under construction. These ponds are not to be confused with the lagoons used for the disposal of industrial wastes in the state for many years. These industrial waste ponds or lagoons have served as a place for storage of processing wastes from vegetable canneries, beet sugar plants, etc., until the period of the year when the stream flows are high and wastes can be discharged safely at a controlled rate into the stream.

The total water surface area of the twenty-one pond projects is about 1,300 acres, or an average of about 62 acres per installation. Plans for other projects, but not yet under construction, will have a total water area of about 300 acres. The sizes of the ponds range from about 5 acres to 335 acres. The area of each installation also includes allowance for wastes from industries in the municipality which, in some cases, is several times the waste from only the domestic sources.

Stabilization ponds have not been used for treatment of raw sewage from small installations such as schools, resorts, subdivisions, etc., although effluent stabilization ponds following secondary treatment have been used where a stable effluent has been required.

A general practice is to locate the ponds at least one-half mile from a municipality and at least one-fourth mile from the nearest dwelling, although several installations are located at distances slightly less than this. All ponds have been designed to provide for an overflow or discharge into a lake, stream or drainage ditch.

In all installations at least two ponds, designed to operate in series, have been provided. The primary pond is sized according to a design five-day BOD loading of fifteen to twenty pounds per acre of water surface. A secondary pond is usually one-fourth to one-half the size of the primary pond. In cases where the area of the primary pond is large, (more than sixty acres) it is recommended that the area be divided into two primary cells designed to operate in series or parallel with each other and in series with the secondary pond. The dikes are from six to eight feet in height above the pond bottom to provide at least three feet of freeboard at maximum liquid level. Provision is made for six months storage of designed winter sewage flows by lowering the level of the ponds during the fall. A minimum depth of one foot of liquid is normally retained in the primary pond. This volume is not considered available as storage capacity. The dikes and bottom of the ponds are constructed of relatively impervious soil or sealed to prevent excess percolation of liquid into the soil. The dikes are constructed with an inner slope of at least four to one and an outer slope of at least three to one.

In only four cases out of the twenty-six designs, has it been feasible to use gravity flow to the primary pond. Others require a pumping station and force main.

Construction costs vary widely depending upon their location, soil characteristics, topography, etc. Availability of a satisfactory site at reasonable cost has frequently been a controlling factor in the feasibility of using ponds. Of sixteen projects for which construction cost figures are available at this time, the average cost of the ponds, including earth moving, overflow structures, fencing, sealing, seeding and access road, was about $940 per acre of $9.40 per design unit of population equivalent, with a range of costs from about $600 to $4300 per acre. The total costs of these projects including interceptor and outfall sewers, pumping stations, land and easements, engineering, fiscal, legal, etc., came to an average of about $3400 per acre or $34 per design population equivalent. Land costs also vary widely and will range up to $500 per acre with an average of about $200 per acre.

---

*Chief, Section of Water Pollution Control, Division of Environmental Sanitation, Minnesota State Department of Health, Minneapolis, Minnesota.

Operation experience has been generally satisfactory, although some problems have been experienced with erosion of the dike at the water line, seepage of liquid through the dikes, and excessive growth of emergent aquatic weeds. Odors have not been a problem except for a few days following the break-up of ice in the spring. This generally occurs in the first two weeks in April. Permanent ice cover will begin to form on the ponds during the early part of November, and ice and snow cover is virtually complete until the spring break-up. Ice thickness of up to eighteen inches has been observed on primary ponds.

Excess loss of liquid due to percolation has not been a problem after the initial filling of the ponds. Also loss by evaporation is not a problem since, on the average, evaporation ranges from ten inches more to ten inches less than precipitation during the period of a year.

WASTE STABILIZATION PONDS IN SOUTH DAKOTA

By

Charles E. Carl and Don C. Kalda*

INTRODUCTION

The terminology applied to the treatment devices under consideration varies with individuals and different areas of the country. The broad term of waste stabilization pond has received rather general acceptance in South Dakota as being most accurately descriptive of the physical and functional mechanisms of such installations. A more specific term often applied to municipal installations is sewage stabilization pond. The term stabilization pond is considered to be synonymous with oxidation pond and stabilization lagoon when defined as "those ponds of regular and controlled shape, depth, and marginal area, specifically designed and constructed as a waste treatment device".

The first stabilization pond installation serving a South Dakota community was placed into operation at Lemmon in 1951. Prior to that time, the State of North Dakota had several satisfactorily operating installations. The success of these early installations attracted much attention in the neighboring states, and their use spread rapidly throughout the midwest area. This method of waste treatment is becoming increasingly popular in South Dakota, and there are now seventy-seven installations treating domestic and organic industrial wastes. Acceptance of this method of waste treatment is demonstrated by the fact that no conventional treatment plants have been built in any municipality in South Dakota under 5,000 population during the last five years.

Rapid acceptance of stabilization ponds in South Dakota can be attributed to a number of important advantages of this treatment method over the conventional processes. A majority of our municipalities have a population of less than 2,500, which size range is particularly adaptable, from an economic and operational standpoint, to the use of stabilization ponds. Significantly reduced costs for sewage treatment has made it possible to finance construction of collection systems in practically all of the smaller municipalities in South Dakota. In addition to reduced costs of construction, operation and maintenance of the treatment facilities, a major advantage of particular importance to pollution control agencies is that the degree of treatment remains at a high level even if the pond is neglected from an operational standpoint. Widespread use of stabilization ponds has unquestionably been a significant factor in accelerating the water pollution abatement program in South Dakota.

Many areas of investigation and development remain to be studied to derive the full advantages of the pond method of waste treatment. Such deficiencies in available data and experience are certainly recognized in our area as new and unexplained conditions develop.

APPLICATION IN SOUTH DAKOTA

All of the stabilization ponds in South Dakota have been installed as permanent waste treatment facilities, and a majority serve as a complete treatment unit. Stabilization pond installations have demonstrated an ability to effectively treat raw sewage under proper loading conditions with no adverse effects. The treatment provided by an installation meeting recommended standards of design is considered to be equivalent to, or better than, that of most conventional secondary treatment plants.

The demonstrated capacity of stabilization ponds to treat raw sewage has resulted in construction of an increased number of such installations in South Dakota. With few exceptions, it is more economical for the smaller municipality to provide additional pond area rather than primary treatment. Many Imhoff tanks have been bypassed when a stabilization pond was constructed in order to eliminate the odors generally associated with such units and also to decrease operational requirements. The ability of stabilization ponds to effectively treat raw sewage has been the significant factor in reducing costs of the smaller installations far below that of conventional plants providing a comparable degree of treatment.

---

*Director, and Assistant Director, Division of Sanitary Engineering, South Dakota Department of Health, Pierre, South Dakota

Stabilization ponds are operating in all sections of South Dakota ranging from the sparsely populated western area to the more densely populated agricultural eastern area. The use of stabilization ponds in South Dakota is not considered limited to sparsely populated areas where low value land is available. For the smaller installations, the aggregate cost of construction and operation of stabilization ponds in high value land areas has generally been found to be significantly less than that of conventional treatment methods. The final choice of treatment method should necessarily be reached by a thorough study of local conditions and economic considerations.

A total of seventy-seven stabilization ponds having a design population of 88,413 persons are presently in operation in South Dakota. The water surface area represented by these installations is 801 acres. Of the total number of stabilization ponds in operation, sixty-one serve municipalities, one serves a State institution, ten serve Federal installations, three serve private installations, and two treat organic industrial wastes. Significant dairy plant wastes are treated in conjunction with domestic wastes in seven of the municipal installations.

Dairy wastes are being treated effectively in conjunction with domestic wastes by stabilization ponds. Organic loadings have been maintained at a level comparable to that recommended for normal municipal installations. A summary of the basis of design for these installations is shown in Table 33.

TABLE 33

BASIS OF DESIGN
DAIRY & MUNICIPAL WASTE STABILIZATION PONDS

City	Design B.O.D. (Pounds/Day)			Area of Pond (Acres)	B.O.D. Loading (Pounds/Acre)
	Domestic	Dairy	Total		
Castlewood	85	100	185	16.0	11
Freeman	150	120	210 (1)	8.3	25
Humboldt	92	112	204	12.3	17
Parkston	220	130	350	15.5	22
Redfield	450	100	550	30.2	18
Scotland	220	48	268	13.1	20
Volga	144	360	390 (2)	21.0	19

(1) Existing conventional plant removes sixty pounds B.O.D./Day.
(2) Existing conventional plant removes 114 pounds B.O.D./Day.

Design loadings for all these installations except Castlewood are in the range of twenty pounds B. O. D. per surface acre per day. A more conservative design was used for the Castlewood pond since it was the first application of a stabilization pond for treatment of combined domestic and dairy wastes in South Dakota. Loadings in the magnitude indicated have resulted in no serious odor problems except in those installations where abusive wastes such as whey and buttermilk have been discharged to the system. The gross organic load from such discharges together with a high sulfate concentration in the water supply created serious odor problems at a number of the installations. Diligent operation of the dairy plant and control by municipal ordinance to prevent such discharges is as necessary for satisfactory stabilization pond operation as it is for a conventional plant.

The discharge of such strong wastes actually creates a lesser problem with a stabilization pond than a conventional plant even though the odor problem may make the situation appear more serious. Reasonably high removals of B. O. D. are accomplished by stabilization ponds even under such adverse conditions and the recovery period to normal operation is generally short. Some problems have been experienced with filling and maintaining an adequate liquid level in the stabilization pond; however, such difficulties have generally been attributed to unsatisfactory soil conditions.

Meat processing wastes from two plants are being treated effectively and economically by stabilization ponds. A loading of fifty ponds B. O. D. per surface acre was used as the basis of design for these installations. A loading of this magnitude is significantly higher than that recommended for treatment of dairy and municipal wastes. Experience has shown that a stabilization pond treating only meat processing plant wastes will operate satisfactorily and provide a high degree of treatment at a loading of fifty pounds B. O. D per surface acre per day. Meat wastes appear to be characteristically well suited for treatment by stabilization ponds. The sulfate concentration of the water supply has also been found to be an important consideration in the design of stabilization ponds particularly when the higher organic loadings are to be applied.

Field and laboratory studies of one of the installations treating wastes from a small packing house showed that the stabilization pond was operating at a loading of ninety-five pounds B. O. D. and 11. 6 pounds total nitrogen per acre per day without creating nuisance conditions. At this loading, the B. O. D. reduction under summer conditions was seventy-two per cent resulting in an average effluent B. O. D. of 150 parts per million. Additional pond area has since been provided for this installation.

A complete listing of the stabilization pond installations in South Dakota is provided in Appendix I.

OPERATIONAL FEATURES AND PERFORMANCE

The mechanism of waste treatment in stabilization ponds has been described many times in the literature. The basic process depends largely on the interactions of bacteria and algae. Bacteria convert the decomposable organic matter to more stable products and in so doing liberate nutrient elements necessary for algal growth. The algae utilize these abundant nutrient materials and through photosynthesis produce the surplus oxygen required for aerobic bacterial action.

During the extended periods of ice and snow cover in the northern areas, the aerobic processes are replaced by anaerobic action. A complete ice cover prevents the escape of odors associated with the anaerobic processes. The transitional period from ice to open water is the most critical time of the year for release of odors.

The degree of treatment obtained in stabilization ponds is considered to be equivalent to that obtained from most conventional secondary treatment plants. From the standpoint of the pollutional load discharged to a watercourse, it is significant to calculate organic reductions in pounds rather than in concentration. Losses in liquid volume through seepage and evaporation significantly reduce the organic load discharged. Studies in North and South Dakota showed that the average minimum reduction in B. O. D. concentration was 70 per cent which occurred during ice cover. Maximum reductions in B. O. D. concentration approached 99 per cent. Reductions in coliform density were found to be 99 per cent or over more than 50 per cent of the time and, with few exceptions, were 95 per cent or more at all times.

DESIGN CRITERIA

Minimum design criteria for stabilization ponds were first developed in South Dakota in 1953. On the basis of experience and additional data on performance, several revisions have been made to the original standards. A copy of the South Dakota Department of Health Design Criteria for Waste Stabilization Ponds is provided in Appendix II.

The basic consideration in the design of stabilization ponds is the organic loading that can be applied to satisfy all conditions. Such conditions are considered to encompass two main objectives in South Dakota; that is, (1) to provide an adequate degree of waste treatment, and (2) to provide such treatment without creating nuisance conditions.

Experience with the early installations in our State has indicated that providing one surface acre per 100 population equivalent (fifteen to twenty pounds B. O. D.) will satisfy both of the above conditions. The surface loading is based on a liquid depth of three to five feet. Such a recommended loading is considerably more conservative than that suggested by some of the other states. Loadings have been held low not particularly for increasing treatment efficiency but to prevent occurrence of nuisance conditions. The lack of odors has become an important factor in the rapidly increasing use of stabilization ponds in South Dakota.

Climatic conditions are necessarily an important consideration in design in our area. Ice cover normally exists from December 1 to March 15. With the loadings recommended, recovery is rapid following ice breakup resulting in only brief periods when odors might occur. The more heavily loaded ponds require increasingly longer periods to revert to the aerobic state.

Experience in South Dakota indicates that the sulfate content of the water supply should be taken into consideration in determining the organic loading of stabilization ponds. A high sulfate content is definitely conducive to more serious odors, and this effect would necessarily be more pronounced in the heavily loaded ponds. There is also some evidence indicating that high sulfate concentrations have a deleterious effect on the efficiency of the stabilization process. Further investigation of this effect on over-all pond operation is required to develop design recommendations; however, observations and experiences to date indicate that sulfate concentrations in the range of 500 parts per million do not cause serious problems. Many of the municipalities in South Dakota served by stabilization ponds use water with sulfate concentrations in excess of 1000 parts per million. Operational problems have occurred at sometime in almost all instances where the sulfate content was at this level. Such problems were not nexessarily limited to those installations having loadings higher than recommended or those treating industrial wastes.

The choice between use of a single cell or multiple cells depends on local conditions, downstream water uses, size of the installations, and other general considerations. Should it be considered necessary to provide one or more cells in series with the primary cell, it is recommended that the loading of the primary cell not exceed the recommended value of fifteen to twenty pounds B. O. D. per surface acre.

Loading based on surface area with controlled depth is considered to be the significant basis for design. Should it be desirable to reduce the size of the primary unit, smaller cells operating in parallel are recommended. Multiple cell design has distinct advantages in many instances. A number of stabilization ponds have been built using a two-level bottom. Approximately half the pond is designed for a liquid depth of three feet and the remainder for a depth of five feet. Such a design has the advantage of alleviating filling problems without increased expenditures for dividing dikes and additional appurtenances.

Location of stabilization ponds with respect to habitation and the municipality is often a subject of discussion. The revised design criteria presently used in South Dakota specifies no minimum distance that a pond should be located away from built-up areas. A study and evaluation of local conditions similar to that necessary to locate a waste treatment plant of any type is considered to be the most practical approach. The results of a 1956 court action in South Dakota regarding the location of a proposed stabilization pond installation may be of interest. The nearest contents of the ponds was proposed to be within approximately 500 feet of a residence, and the owner brought suit to prevent construction of the installation. After hearing testimony for two days, the court ruled against the property owner. The installation was placed into operation in early 1957 and no further legal action has been initiated.

COSTS

Cost data for a majority of the installations in South Dakota is provided in Appendix III. The average construction cost based on sixty-two installations with a total design population of 83,811 and varying in design population from 200 to 10,600 is $11.00 per capita. The range of such costs is from a minimum of $3.27 per capita to $37.94 per capita. The construction cost in terms of water surface averaged $1185.00 per acre with a range from $634.00 to $3690.00 per acre. Land costs are extremely variable and dependant on local conditions. The data shows an average land cost of $2.58 per capita based on land purchases by forty-six municipalities with a total design population of 63,582 persons. The total approximate average cost of providing sewage stabilization ponds in South Dakota is indicated to be $13.58 per capita.

The equivalent of complete treatment was therefore provided at approximately the same or at a lesser cost than that of conventional primary treatment. When operation and maintenance costs over an extended period are also considered, the savings in cost through use of stabilization ponds becomes even more pronounced.

OPERATIONAL PROBLEMS

Odor problems have occurred in a number of the installations in South Dakota. A serious odor problem developed in one of the earliest installations in the State serving the City of Kadoka. The most serious conditions prevailed during the summer season when it would be expected that stabilization ponds would perform at peak efficiency and be capable of assimilating heavy loads. Studies indicated that the loading was in the order of twenty pounds B.O.D. per surface acre per day. Sulfides continued to be produced through the open water seasons indicating that anaerobic decomposition was taking place. The municipal water supply has a sulfate concentration of 1038 parts per million and total dissolved solids of 1841 parts per million. Investigations resulted in no specific conclusions on the cause of the unsatisfactory conditions. A second cell was constructed in early 1956 to provide a loading of approximately twelve pounds, B. O. D. per surface acre. The installation has functioned without serious nuisance conditions since that time although some odor problems have been reported.

Problems with odors have also been experienced particularly during the spring transition period from ice to open water in a number of other installations. Particular difficulties have been experienced with those installations treating dairy wastes in conjunction with domestic sewage. Investigation of these problems has shown that abusive wastes such as buttermilk or whey have been discharged to the system. Experience has shown that stabilization ponds can effectively treat dairy wastes under proper loading conditions. It is also significant that the most serious problems occurred where the municipal water supply contained sulfates in the order of 1000 parts per million.

No use has been made of nitrate compounds for control of odors. Very limited use has been made of odor masking compounds. Observations made at one installation using such a compound indicated that the material was ineffective at the dosage being applied.

Control of weeds during the initial filling period often causes operational problems. Proper design and construction can alleviate this problem to a large extent. Some success has been demonstrated in controlling aquatic vegetation by applying some of the newer types of herbicides.

Sealing of the bottom and embankments is essential when ponds are constructed of pervious soil. Heavy growths of vegetation have developed in some installations constructed in porous soils resulting in greatly increased maintenance requirements. Limited use has been made of bentonite and asphaltic sealants in South Dakota. The one experience with bentonite for sealing the bottom of a pond constructed in extremely sandy soil was not satisfactory. An asphaltic compound was used to seal one cell of another installation and the facility has not been in use for a sufficient period of time to properly evaluate its effectiveness.

Operational problems have been limited to a small number of the total installations in operation. Some odors are experienced during the transition period from ice to open water in almost all installations. The recovery period is necessarily of longer duration for the more heavily loaded ponds. Alternate freezing and thawing further aggravates the recovery process. Ponds have been placed into operation in early winter with no difficulties experienced. Insect breeding in properly constructed and maintained ponds has presented no serious problems. There was one instance of a high mosquito population at a pond that developed a dense cover of vegetation before acquiring an optimum depth of water. Since an adequate water level has been maintained and vegetation brought under control, the problem no longer exists.

CONCLUSION

Waste stabilization ponds have become an answer to the rising costs of sewage treatment for a great percentage of the municipalities in South Dakota. Further application of stabilization ponds as a complete treatment device for many organic industrial wastes will bring about further advances in water pollution control in our State. Stabilization ponds have fulfilled a long recognized need for effective treatment at reasonable cost for the smaller municipalities and industries.

REFERENCES

1. "Sewage Stabilization Ponds in South Dakota - 1960." A bulletin of the South Dakota State Department of Health; Pierre, South Dakota.
2. "Sewage Stabilization Ponds in the Dakotas - 1957." A Joint Report by the Public Health Service, North Dakota Department of Health and South Dakota Department of Health; Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.
3. "Waste Stabilization Lagoons - Design, Construction, and Operation Practices Among Missouri Basin States - 1959." A Committee Report of the Missouri Basin Engineering Health Council.
4. "Sewage Stabilization Ponds - 1959." An unpublished paper by Charles E. Carl presented to School of Public Health Seminar; University of Minnesota; Minneapolis, Minnesota.
5. "Waste Stabilization Ponds in South Dakota - 1957." An unpublished paper by Don C. Kalda presented at Texas Water and Sewage Works Short Course; College Station, Texas.
6. Official Files of the Division of Sanitary Engineering; South Dakota Department of Health; Pierre, South Dakota.

APPENDIX I
STABILIZATION PONDS IN SOUTH DAKOTA

Location	1950 Pop.	Design Pop.	Date Constructed	No. Cells	Size in Acres	Kind of Sewage	Remarks
			------------MUNICIPALITIES------------				
1. Belle Fourche	3540	5200	1960	2	22.9-29.1	Raw	Parallel Operation
2. Beresford	1686	1686	1955	2	8.5-8.0	Raw	Series Operation
3. Bison	457	457	1954	1	1.0	Raw	
4. Bonesteel	485	540	1955	1	5.4	Raw	
5. Bowdle	781	860	1957	1	8.6	Raw	
6. Britton	1430	2300	1959	2	11.0-11.5	Raw	
7. Burke	829	829	1953	2	4.8-3.4	Primary	Series or Parallel Operation
8. Canton	2530	3000	1957	2	15.0-15.0	Raw	Series Operation
9. Castlewood	497	1500	1957	2	7.6-8.4	Raw	Series or Parallel Operation
10. Chancellor	193	200	1959	1	2.0	Raw	Dairy & Municipal Wastes
11. Claremont	236	282	1960	1	2.6	Raw	
12. Clear Lake	1105	1200	1953	1	12.0	Raw	
13. Colton	521	616	1958	1	6.2	Raw	
14. Conde	409	500	1959	1	5.0	Raw	
15. Cresbard	235	300	1959	1	3.0	Raw	
16. Eagle Butte	375	850	1957	1	8.4	Raw	
17. Edgemont	1151	2000	1958	1	20.4	Raw	
18. Elk Point	1366	1600	1958	1	16.0	Raw	
19. Faulkton	837	900	1959	1	9.0	Raw	
20. Freeman	940	1100	1956	1	10.0	Raw	Dairy & Municipal Wastes
21. Garretson	745	840	1959	2	4.0-4.3	Raw	Series or Parallel Operation
22. Gettysburg	1555	2000	1955	2	12.0-8.0	Raw	Series Operation
23. Groton	1084	1400	1958	1	14.6	Raw	
24. Hayti	413	500	1953	2	2.6-2.3	Raw	Series or Parallel Operation
25. Howard	1246	1500	1958	2	7.6-7.4	Raw	Series or Parallel Operation
26. Humboldt	450	1230	1958	1	12.3	Raw	Dairy and Municipal Wastes
27. Isabel	511	511	1955	1	2.7	Raw	
28. Kadoka	584	820	1953	2	5.2-3.0	Raw	Series or Parallel Operation
29. Kennebec	374	400	1959	2	2.0-2.0	Raw	Series or Parallel Operation
30. Kimball	952	1000	1960	2	5.0-5.0	Raw	Series or Parallel Operation
31. Langford	456	530	1956	1	5.3	Raw	

APPENDIX I
STABILIZATION PONDS IN SOUTH DAKOTA (Continued)

Location	1950 Pop.	Design Pop.	Date Constructed	No. Cells	Size in Acres	Kind of Sewage	Remarks
			------------MUNICIPALITIES------------				
32. Lemmon	2760	2800	1951	1	25.0	Raw	
33. Leola	772	1350	1960	1	12.0	Raw	
34. McLaughlin	713	970	1960	1	9.7	Raw	
35. Mission	388	400	1957	2	2.3-1.8	Raw	Series or Parallel Operation
36. Morristown	190	300	1959	1	3.0	Raw	
37. Murdo	739	930	1956	1	9.3	Raw	
38. New Effington	367	370	1954	2	2.0-1.7	Raw	Series or Parallel Operation
39. Newell	784	1000	1959	2	5.0-5.0	Raw	Series or Parallel Operation
40. Onida	816	1150	1958	1	11.5	Raw	
41. Orient	205	205	1959	1	2.0	Raw	
42. Parkston	1354	1550	1957	1	15.5	Raw	Dairy & Municipal Wastes
43. Philip	810	810	1953	2	3.2-2.7	Raw	Series Operation
44. Pollock	400	500	1955	2	2.3-2.3	Raw	Series Operation
45. Redfield	2655	3020	1955	1	30.2	Raw	
46. Scotland	1180	1200	1959	2	6.7-6.4	Raw	Dairy & Municipal Wastes
47. Selby	700	975	1958	2	5.2-4.8	Raw	Series or Parallel Operation
48. Sisseton	2871	2871	1955	2	16.0-11.0	Raw	Series Operation
49. Springfield	800	1800	1957	2	7.7-11.0	Raw	Series or Parallel Operation
50. Summit	431	400	1959	2	3.6-2.1	Raw	Series Operation
51. Tabor	373	490	1956	1	4.9	Raw	
52. Valley Springs	389	530	1955	2	3.8-2.0	Raw	Series Operation
53. Veblen	476	476	1954	2	1.3-1.2	Primary	Series Operation
54. Volga	578	2100	1959	3	7.0-7.0-7.0	Treated	Dairy & Municipal Wastes
55. Wagner	1528	1900	1958	1	21.0	Raw	
56. Wall	556	1100	1951	1	8.9	Raw	
57. Watertown	12699	10600	1960	2	30.0-23.8	Secondary	Polishing Ponds
58. Webster	2503	3200	1960	2	16.5-16.5	Raw	Series or Parallel Operation
59. White River	465	500	1956	1	5.0	Raw	
60. Whitewood	304	420	1958	1	4.2	Raw	
61. Wilmot	583	750	1958	1	7.5	Raw	

APPENDIX I
STABILIZATION PONDS IN SOUTH DAKOTA (Continued)

Location	1950 Pop.	Design Pop.	Date Constructed	No. Cells	Size in Acres	Kind of Sewage	Remarks
------------STATE INSTALLATIONS------------							
62. Redfield State Home	850	2300	1960	2	11.9-11.9	Raw	Series or Parallel Operation
------------FEDERAL INSTALLATIONS------------							
63. Badlands National Monument		220	1957	2	1.0-1.0	Raw	Fluctuating Population
64. Cherry Creek Indian School		60	1953	2	0.2-0.2	Primary	Septic Tank Effluent
65. Gettysburg Radar Station		175	1955	2	0.7-0.7	Raw	Series or Parallel Operation
66. Kyle Indian School		100	1957	2	0.5-0.5	Raw	Parallel Operation-Day School
67. Oahe Administration		100	1954	2	0.5-0.4	Raw	Population Fluctuates
68. Pierre Indian School		500	1956	1	5.1	Raw	
69. Pickstown		280	1958	1	2.6	Raw	
70. Red Scaffold Indian School		40	1957	2	0.2-0.2	Raw	
71. Rosebud Boarding School		200	1954	4	0.2-Each	Primary	Septic Tank Effluent
72. White Horse Indian School		75	1953	2	0.2-0.2	Primary	Septic Tank Effluent
------------INDUSTRIAL INSTALLATIONS------------							
73. Greenlee Packing Co.		1850	1954	3	2.5-3.8-1.7	Primary	Meat Packing Plant
74. Hill Packing Co.		825	1958	1	2.8	Raw	Horse Slaughtering Plant
------------PRIVATE INSTALLATIONS------------							
75. Bethesda Home	150	180	1956	1	1.8	Raw	
76. Wasta	140	140	1953	1	0.5	Primary	Septic Tank Effluent
77. Weaver	50	50	1955	1	0.5	Raw	

APPENDIX II
SOUTH DAKOTA DEPARTMENT OF HEALTH

DESIGN CRITERIA FOR SEWAGE STABILIZATION PONDS
1960

A. General

1. A preliminary report for proposed sewage stabilization pond installations should be submitted for review prior to preparation of final plans. This report shall include the shape of the cell(s) (B-4), a description of soil characteristics as revealed by test borings (E-3), size, location, and other such proposed design features.

2. The review of proposed stabilization pond installations will be carried out on an individual basis with local conditions taken into consideration.

3. All plans and specifications shall be submitted at least 30 days prior to date upon which action by the approving authority is desired.

B. Design

1. Original construction should provide at least one surface acre per one-hundred (100) population plus the industrial waste population equivalent, if significant. In terms of B. O. D., a loading of 20 pounds per surface acre should not be exceeded. Due consideration should be given possible future municipal expansion and/or additional sources of wastes when the original land acquisition is made.

2. The choice between the use of single cell and multiple cell ponds will be dictated on the basis of local conditions and downstream water use. Where a greater degree of treatment is necessary or desirable, one or more cells in series may be added to the primary cell; provided, however, that the primary cell should have a surface area equal to that set forth in B-1.

3. Where ponds of one or more cells follow some type of conventional treatment device, the requirements in B-1 may be reduced to compensate for the B. O. D. reduction in the pre-treatment unit(s).

4. The shape of all cells should be such that a uniform perimeter results. No islands or peninsulas will be permitted.

C. Location

1. Ponds should be located at a practical distance away from built-up areas with due respect given to possible future expansion of the city.

2. Locating ponds in watersheds receiving significant amounts of runoff water is discouraged unless adequate provisions are made for storm water to by-pass the ponds.

3. In locating ponds, preference should be given sites which will permit an unobstructed wind sweep across the ponds, especially in the direction of the local prevailing winds.

4. Proximity of ponds to water supplies and other facilities subject to contamination should be critically evaluated to avoid creation of health hazards or other undesirable conditions.

D. Embankments and Dikes

1. Compacted embankments of impervious materials should be constructed.

2. Minimum embankment top width should be 8 feet. Lesser top width will be considered for very small installations.

3. Maximum embankment slopes should not be steeper than:

    a. Inner - 3 horizontal to 1 vertical (preferably 4 or 5 or 1).

    b. Outer - 3 horizontal to 1 vertical.

4. Minimum embankment slopes should not be flatter than:

    a. Inner - 6 horizontal to 1 vertical.

    b. Outer - not applicable, except that significant volumes of surface water should not enter the ponds.

5. Minimum freeboard should be 3 feet plus frost heave.

6. Minimum normal liquid depth should be 3 feet.

7. Maximum normal liquid depth should be not more than 5 feet. For ponds with surface areas of more than 10 acres, special consideration will be given to maximum liquid depths greater than 5 feet provided such depths are minimal in area.

8. Embankments should be seeded, except below the water line. Aflalfa should not be included in seed mixtures since the long roots of this plant are apt to impair the water-holding efficiency of the dikes. Additional protection for embankments (rip-rap) may be necessary as soil conditions and pond size warrant.

E. Pond Bottom

1. The pond bottom should be as level as possible at all points. Shallow or feathering fringe areas usually result in locally unsatisfactory conditions.

2. The bottom should be cleared of vegetation and debris. Organic material thus removed should not be used in embankment construction.

3. Soil formations should be relatively tight to avoid undue liquid losses through percolation of seepage. Soil borings to determine soil characteristics shall be made a part of preliminary surveys to select pond sites.

F. Influent Lines

1. Any generally accepted material for pond piping will be given consideration but the material selected should be adapted to local conditions. Special consideration should be given to the character of the wastes, possibilities of septicity, exceptionally heavy external loadings, abrasion, the necessity of reducing the number of joints, soft foundations, and similar problems.

2. The influent line into single-celled ponds should be essentially center-discharging. Influent lines into the primary section of multiple-celled ponds should be essentially center-discharging, but this does not apply to those cells following the primary cell in series operation.

3. Gravity inlet lines should be designed to discharge horizontally. Pressure inlet lines may discharge vertically, however, the end of the pipe should be located approximately one foot above the bottom of the pond and should not extend to an elevation such that ice will damage the terminal structure during winter operations.

4. The end of the discharge line should rest on a suitable concrete apron with a minimum size of two feet square. Larger aprons and influent piping supports are suggested in cases where the soil is unstable. Flow splitters or dispersing devices are also desirable where a horizontal type of influent line terminal structure is utilized.

5. Influent and effluent piping should be located to minimize short circuiting within the pond.

6. Manholes or clean-outs are recommended where pipes pass through the embankment.

7. Influent lines should be placed in or near the bottom. The use of exposed dikes carrying influent lines to the center of the pond will not be approved.

G. Interconnecting Piping and Overflows

1. Interconnecting piping and overflows should be of suitable material of ample size. The use of frost proof overflow manholes or valve boxes for controlling liquid levels in the pond is recommended. Multiple influent lines to such structures should be provided and arranged so that overflows will ordinarily come from, at, or near the surface of the pond. The lowest of the multiple influent lines to such manholes or structures should be at least twelve inches off the bottom to control eroding velocities and to avoid pick-up of bottom deposits. Means for draining the pond are recommended particularly for the larger installations.

2. Overflow lines should discharge onto anchored concrete slabs. These lines should be vented if siphoning may be developed.

H. Miscellaneous

1. The pond area should be adequately fenced with a stock-tight fence.

2. Appropriate signs should be provided to designate the nature of the facility.

3. Provisions for flow measurement should be provided. Facilities for installation of a weir would be adequate for most installations.

I. Industrial Wastes

1. Ponds for industrial waste require special planning and study, and these suggested minimum standards may not apply. The South Dakota Department of Health should be consulted on such problems before the design phase is completed.

APPENDIX III
COST DATA - STABILIZATION PONDS IN SOUTH DAKOTA

Town	1950 Population	Design Population	Date of Completion	Size (Acres)	Number of Cells	LAND		Project Construction Cost				
						Acres Acquired	Total Cost ($)	Treatment Unit Cost ($)	Per Capita Treatment Unit Cost ($)	Earth Moving		
										Cubic Yards	Cost Per Yd. ($)	Total Cost ($)
Belle Fourche	3540	5200	1960	52.0	2	80	7,500	35,558.	6.82	188,100	.12	22,572.
Beresford	1686	1686	1955	16.5	2	160	City Owned	17,265.	19.12	95,000	.14	13,300.
Bonesteel	485	540	1955	5.4	1	11	2,300	10,235.	21.29	30,500	.20	6,100.
Bowdle	781	860	1957	8.6	1	160	City Owned	10,546.	12.26	35,175	.18	6,331.
Britton	1430	2300	1959	22.5	2		City Owned	18,502.	8.07	85,000	.15	12,750.
Burke	829	829	1953	8.2	2	10	2,500	7,450.	8.99	16,500	.30	4,950.
Canton	2530	3000	1957	30.0	2		City Owned	24,582.	8.19	70,000	.17	11,900.
Castlewood	497	1500	1957	15.0	2	25		18,000	12.00	Lump Sum		
Chancellor	193	200	1959	2.0	1	4	1,000	6,433.	32.17	20,000	.20	4,000.
Claremont	236	282	1960	2.6	1		City Owned	4,906.	17.42	14,300	.24	3,400.
Clear Lake	1105	1200	1953	12.0	1	18.2	1,366	12,571.	10.47	40,000	.18	7,200.
Colton	521	616	1958	6.2	1	12.75	4,462	19,787.	32.12	23,000	.21	4,830.
Conde	409	500	1959	5.0	1		City Owned	5,150.	10.30	13,000	.20	2,600.
Cresbard	235	300	1959	3.0	1	9.0	1,000	11,083.	36.85	33,400	.18	6,012.
Eagle Butte	375	850	1957	8.4	1	20.2	1,012	8,618.	10.73	Lump Sum		6,834.
Edgemont	1151	2000	1957	20.4	1	40	3,000	10,890	5.45	40,500	.20	8,100.
Elk Point	1366	1600	1958	16.0	1	58	3,550	18,500.	11.56	60,000	.20	12,000.
Faulkton	837	900	1959	9.0	1		5,400	16,415.	18.20	71,363	.15	10,704.
Freeman	940	1100	1956	10.0	1	10	4,000	8,425.	7.65	25,000	.14	3,425.
Garretson	745	840	1958	8.3	2	14	3,152	15,771.	18.78	57,250	.18	10,305.
Gettysburg	1555	2000	1955	20.0	2	40	2,000	20,131.	10.06	82,000	.18	14,760.
Groton	1984	1400	1958	14.6	1		City Owned	16,926.	12.09	86,500	.13	10,985.
Hayti	413	500	1953	5.0	2	11	1,100	15,670.	37.94	25,350	.34	8,619.
Howard	1246	1500	1958	15.0	2	35.7	4,550	15,200.	10.13	59,000	.20	11,800.
Humboldt	450	1230	1958	15.0	2	22.0	6,000	10,688.	8.67	34,875	.18	7,523.
Isabel	511	511	1955	2.7	1	5	City Owned	7,000.	13.70	8,000	.22	1,760.

APPENDIX III
COST DATA - STABILIZATION PONDS IN SOUTH DAKOTA (Continued)

Town	1950 Population	Design Population	Date of Completion	Size (Acres)	Number of Cells	Land		Project Construction Cost				
										Earth Moving		
						Acres Acquired	Total Cost ($)	Treatment Unit Cost ($)	Per Capita Treatment Unit Cost	Cubic Yards	Cost Per YD. ($)	Total Cost ($)
Kadoka	584	820	1953	8.2	2	14	City Owned	11,500.	14.38	10,000	.28	2,846.
Kennebec	374	400	1959	4.0	2	8	1,650	12,735.	31.09	47,700	.19	9,063.
Kimball	952	1000	1960	10.0	2		City Owned	15,035.	15.03	42,000	.15	6,375.
Langford	456	530	1956	5.3	1	9.16	1,250	3,869.	7.74	22,000	.14	3,080.
Lemmon	2760	2800	1951	25.0	1	35	2,000	31,000.	11.23	45,572	.40	19,028.
Leola	772	1350	1960	12.0	1		City Owned	18,088.	13.40	87.500	.19	16,187.
McLaughlin	713	970	1960	9.7	1	13	4,000	26,000	26.60	84,800	.20	17,264.
Mission	388	400	1957	4.0	2	20	2,000	11,081.	27.70	Lump Sum		6,500.
Morristown	190	300	1959	3.0	1		City Owned	4,631.	15.42	13,850	.16	2,216.
Murdo	739	930	1955	9.3	1	143	12,000	12,000	12.90	57,700	.19	10,963.
New Effington	367	370	1954	3.7	2			6,524.	17.62	14,384	.38	5,465.
Newell	784	1000	1960	10.0	2	20	1,200	12,177.	12.17	38,000	.17	6,460.
Onida	816	1150	1958	11.5	1		City Owned	18,368.	15.97	Lump Sum		13,500.
Orient	205	205	1959	2.0	1	5	1,200	5,703.	27.82	20,000	.20	4,000.
Parkston	1354	1550	1957	15.5	1	36	8,500	28,829.	18.59	150,000	.16	24,000.
Philip	810	810	1953	5.7	2	6	1,000	4,276.	4.27	6,890	.35	2,412.
Pollock	400	500	1955	5.0	2	9.5	950	12,713.	25.42	24,500	.23	5,635.
Redfield	2655	3020	1955	30.2	1	87	8,700	26,960.	8.92	105,000	.19	19,950.
Redfield Home	850	2300	1960	23.8	2		State Owned	18,864.	8.20	Lump Sum		12,000.
Reliance	225	350	1960	3.0	1	5	500	5,628.	16.06	9,300	.24	2,232.
Scotland	1180	1500	1959	13.1	2	40	4,500	11,566.	7.70	62,000	.17	10,230.
Selby	700	975	1958	10.0	2	27	1,883	11,514.	11.81	36,700	.17	6,239.
Sisseton	2871	2871	1955	27.0	2	45	12,375	29,764.	10.39	122,900	.16	20,360.
Springfield	800	1800	1957	19.6	2	26.5	3,710	20,500	10.25	Lump Sum		
Summit	431	400	1959	5.7	2	12	1,100	15,105.	30.20	30,000	.16	4,800.
Tabor	373	490	1956	4.9	1	6.8	1,360	2,560.	5.22	12,000	.20	2,400.

APPENDIX III

COST DATA - STABILIZATION PONDS IN SOUTH DAKOTA (Continued)

Town	1950 Population	Design Population	Date of Completion	Size (Acres)	Number of Cells	Land		Project Construction Cost				
						Acres Required	Total Cost ($)	Treatment Unit Cost($)	Per Capita Treatment Unit Cost	Earth Moving		
										Cubic Yards	Cost Per Yd. ($)	
Valley Springs	389	530	1955	5.3	2	15.9	3,270	9,750.	18.39	45,000	.17	7,650.
Veblen	476	476	1954	2.5	2	12	1,200	5,856.	12.30	12,600	.31	3,906.
Volga	578	2100	1959	21.0	3	62	15,000	26,603.	12.68	96,700	.15	14,500.
Wagner	1518	1900	1958	21.0	1	40	7,000	21,117.	11.11	65,400	.145	9,483.
Wall	556	1100	1951	10.9	2	25	City Owned	15,000.	13.63	6,975	.35	2,411.
Watertown	12699	10600	1960	53.8	2	80	19,257	34,701.	3.27	125,000	.15	18,750.
Webster	2503	3200	1960	31.0	2	46	7,680	24,408.	7.62	114,560	.15	17,527.
White River	465	500	1956	5.0	1	20	1,000	18,950.	37.90	Lump Sum		
Whitewood	304	420	1958	4.2	1	7.8	235	6,607.	15.73	23,000	.20	4,687.
Wilmot	583	750	1958	7.5	1	23.7	1,000	14,578.	19.44	38,500	.23	8,855.

Note: Per Capita cost is based on design populations.

LAGOON OPERATING EXPERIENCE IN IOWA

R. J. Schliekelman*

In Iowa, the use of waste stabilization ponds for treating raw sewage has become quite popular among the smaller communities where the provision of conventional sewage treatment sometimes is a great financial burden. This mode of treatment was not definitely encouraged as was done in the early 50's in the Dakotas. It was felt that a number of factors were not as favorable for Iowa conditions as compared with the Dakotas which had the greatest experience with the method. Soil characteristics sometimes were not as favorable due to the glacial sand and gravel deposits prevalent in the northern areas of Iowa. Heavier farm density has made the selection of sites with suitable isolation from habitation more difficult. Finally, higher land costs, commonly in the $300-$500 per acre range, serve to decrease somewhat the cost advantage of the lagoon method of treatment.

One temporary lagoon serving a 60-home housing development was constructed in 1954, but the first municipal lagoon was not constructed until 1956. Since that time, the waste stabilization lagoon has been growing in popularity and as of June 30, 1960, a total of 36 lagoons were in operation or under construction. Of this total, 22 lagoons are serving municipalities with the remainder of 14 serving miscellaneous installations, such as housing developments, mobile home parks, camps, and others. In addition, another 42 lagoon installations are in the planning stage with plans approved or preliminary engineering reports submitted. At the present time, the 22 municipal installations are only a small percentage of the 346 municipalities with sewage treatment.

It is of interest to note that 15 of the 22 municipal installations are serving communities with new sanitary sewer systems. We feel that the public health and other benefits accruing from a sanitary sewer system would not have been possible in many of these communities without the relatively lower cost of the lagoon method of treatment.

While the experience of Iowa with the lagoon is not as extensive as the other states with more installations, a brief summary of experiences and design and operation practices may be helpful. However, only factors which are deemed particularly significant will be discussed.

Our state has benefitted from the experience of the other states in the Missouri River Basin and as a result all of our completed installations have operated quite successfully. The South Dakota Department of Health Design Criteria for Sewage Stabilization Ponds was first used as a guide for general design features. Tentative standards based on a draft of the lagoon section of the GL-UMR "Standards for Sewage Works" were drawn up in 1958.

Area Loadings

Surface area is one of the basic considerations in the design of waste stabilization lagoons. Population loadings of 100 persons per acre, or 20 lbs. of BOD per acre, have been used for design in Iowa. As in the Dakotas, the critical period for aerobic conditions occurs during the transition from ice cover to open water. To prevent, or minimize, possible odor complaints, these aerobic conditions must be established as rapidly as possible. Dakota experience indicated a minimum recovery period with the 20 lbs. of BOD loading, and this figure has also been adopted by Iowa.

---

*Public Health Engineer, Iowa Department of Public Health.

Undoubtedly, this loading is conservative but will be used in the majority of installations until experience indicates that heavier loadings will produce satisfactory results under winter operation or spring ice breakup conditions. Observations of a limited number of lagoons during the transition period in the spring have indicated little or no odors or complaints.

Design loadings of school lagoon installations have been based on the principle of complete retention of all flows during the school year with some allowance for seepage and evaporation losses. An area requirement of 0.1 acre per 100 pupils with a water usage of 10 gallons per capita was calculated and other water usage figures are in direct ratio. Available BOD figures for schools indicate this approach would give the proper BOD loading.

Overflow Structures

For maximum flexibility in operation, the overflow structure should provide for varying the pond operating levels. The most common structure is a manhole divided by a wall containing stop planks. An influent line at the 2'-3' depth and a lagoon drain line leading to this manhole provides, a means of regulating the depth between maximum depth and complete drainage.

In northern climates, the overflow structure must be so designed that ice formation will neither stop the overflow or damage the structure.

Multiple Cells

Visits to other states indicated considerable difficulty in maintaining a satisfactory liquid depth in single cell installations, with resultant odors and excessive weed growths. Benefitting from this experience, our State has required two cells in most large installations and that they be capable of being operated either in series or in parallel. With ponds designed to operate in parallel it is possible to divert all flow to one pond where the community is installing a new sewer system or the water usage is low.

For lagoons operated in series the entire organic load will be applied to the primary unit. However, we have not required an increase in total area since we visualize series operation for better B.O.D. and coliform reduction and a lower algal content in the effluent during summer months when higher loadings on the primary unit can be tolerated. On the other hand parallel operation during the winter months would produce the lightest loading in each pond and facilitate aerobic recovery during the spring transition period.

Soil Permeability

The absence of a method for determining the expected permeability of the soil in the bottom and embankments of waste stabilization ponds is becoming more significant with the increasing use of this method of treatment. Fortunately, all of our installations have been relatively impermeable and satisfactory water levels have been maintained. Soil borings have been required and planning for sealing with clay has been facilitated by this means. Possibly, adequate compaction has been a factor, since all specifications have called for sheep-foot rolling.

Construction Costs

Comparison of stabilization lagoon construction costs with conventional treatment costs show a markedly lower per capita cost for the lagoons. Cost data, however, has not been thoroughly analyzed to include consideration of relative land costs and operation and maintenance requirements.

Per capita lagoon construction costs have varied from a low of $7 to $38 with earth moving costs varying from 18¢ to 39¢ per cubic yard. Land costs have ranged from $250 to over $700 per acre.

Industrial Application

Industrial applications have been rather limited except for the treatment of domestic sewage from the plants. Creameries contribute up to about one-third of the BOD loading of a number of municipal lagoon installations without adverse effects. Construction is nearing completion on a large milk plant which will employ a high rate trickling filter followed by a waste stabilization lagoon. Treatment results will be followed closely.

During a two-year period ending in April 1956, pilot plant studies were carried out by an Iowa meat packing plant on combined anaerobic-aerobic treatment. Excellent results were obtained and the process will be discussed by Mr. F. W. Sollo of Swift and company in a paper on Wednesday. Reduction in land requirements possible with the anaerobic process may stimulate its development for use with other wastes.

In conclusion, we feel that the efficacy of the waste stabilization lagoon has been demonstrated by wide experience. On the basis of raw sewage loadings established in the Dakotas, the required land area may preclude use of these facilities in some localities. Unless heavier loadings can be demonstrated as practical for climates, it is expected that the statilization lagoon will find its greatest use in the smaller community.

WASTE STABILIZATION PONDS IN KANSAS

by

Russell L. Culp*

Introduction

In relating the Kansas experience with waste stabilization ponds, an attempt will be made to avoid repetition of other material presented here, and emphasis will be placed on conditions and practices which may differ from those in other areas.

The first waste stabilization pond in Kansas for the treatment of raw municipal sewage was built at Frankfort in 1956. Prior to that time oxidation ponds had been incorporated as a part of sewage treatment works in 24 Kansas communities, the first of these being constructed at Mt. Hope in 1937. All of these early oxidation ponds received treated or partially treated municipal wastes, and all of them functioned very well with little operating attention. At present there are 53 waste stabilization ponds in the state which are designed as the sole method of sewage treatment. They have had an appeal to the small community because of their low initial cost where land is cheap, their ease of operation, and their low maintenance costs. Waste stabilization ponds have filled a special need in fringe areas for temporary treatment works. They have often been used to serve the initial development in an area until property values reached a level which would support a large sewer district with the necessary trunk sewers and conventional treatment facilities.

Uses

Ponds can be utilized to serve a variety of purposes in the treatment of waste waters:

1. The principal use of waste stabilization ponds is for the complete treatment of sewage within the pond cells.
2. Oxidation ponds may be used for tertiary treatment following trickling filters and final settling basins. In Kansas the BOD load on oxidation ponds used for tertiary treatment is calculated by use of the N. R. C. formula, but for this purpose the maximum allowable pretreatment efficiency is taken as 80 percent.
3. Oxidation ponds have been used for secondary treatment in special situations, but these are exceptions to the general practice of following conventional primary facilities with conventional secondary units.
4. Oxidation ponds have been used in lieu of final settling basins in two instances, but again this is uncommon, and conventional final tanks apparently are preferred because they are better adapted to recirculation and control of the hydraulic loading applied to trickling filters.
5. At one conventional sewage treatment plant a waste stabilization pond is used to receive storm water overflows, thus avoiding the by-passing of untreated storm flows to the receiving watercourse.
6. During the course of housing development in some areas, waste stabilization ponds have served dual purposes. After initial temporary use as the only means of sewage treatment, lagoons have subsequently been converted to use as oxidation ponds for tertiary treatment following a conventional plant.
7. Waste stabilization ponds have been used to a limited extent for treating creamery wastes along with about equal volumes of domestic wastes.

---

*Chief, Water Supply Section, Division of Sanitation, State Board of Health

8. Oxidation ponds have been widely used in Kansas as one process in the treatment of oil refinery wastes.

Design Considerations

In designing waste stabilization ponds, site selection is a critical feature. The distance to houses should be the same as for other types of sewage treatment facilities even though the process appears to have less nuisance potential. The direction of prevailing winds is another factor in pond location. Finding sufficient areas of suitable terrain which are free from flooding has presented a special problem at some Kansas sites, but for permanent facilities, this type of site is required. For temporary ponds some flooding risk can be taken.

The extreme variability of rainfall and evaporation in Kansas is a significant factor in the planning of waste stabilization ponds. Consideration must be given to the maintenance of minimum water depths of 2 to 3 feet over an area large enough to permit aerobic treatment of the wastes. During an average year the net water loss (evaporation minus rainfall) from a water surface amounts to 5 inches at the eastern Kansas border and to about 50 inches in the southwestern corner of the state. Years of maximum evaporation and minimum rainfall often coincide and the net water loss can be as much as 30 inches in the eastern Kansas and 82 inches in the southwestern part of the state. Another critical factor in maintaining water levels is the necessity to limit seepage from the ponds to 1/4 inch per day.

To give some insight into the maintenance of adequate water levels, calculations have been made of the minimum quantity of sewage discharge required to ponds in terms of gallons per capita per day. This was done on the basis of an actual connected load of 160 persons per acre of pond and seepage of 1/4" per day. In an average year the total requirements vary from 45 to 75 gallons per capita per day, east to west across the state. In the driest years, sewage flows of 60 to 90 gallons per capita per day are needed. This means that single cell ponds can be used only in the eastern 1/4 of Kansas, and that 2 or 3 cells must be used in other parts of the state. The importance of controlling seepage is emphasized by the fact that 42 1/2 gallons per capital per day of these total inflow requirements are needed to compensate for the 1/4 inch per day of seepage.

To control seepage, three types of pond seals have been successfully used: compacted select clays and bentonite and polyphosphate admixtures. When bentonites are used, they are applied to the scarified bottom of the pond at the rate of 5 to 11 tons per acre, then wetted and compacted. The usual cost of sealing with bentonite is about 1.5 to 3.0 cents per square foot.

In Kansas the maximum recommended loading for permanent waste stabilization ponds receiving domestic sewage is 27 pounds of 5-day BOD per acre per day. For interim ponds the upper limit is 51 pounds. Actual loadings in Kansas vary from 16 to 51 pounds for waste stabilization ponds, although a few oxidation ponds receive heavier loadings. The actual loading on the oxidation pond at Lincoln is 135 pounds. Nearly 20 years' experience with this pond indicates that it remains aerobic throughout the year. Although some states give no credit for secondary ponds when the ponds are operated in series, Kansas does. It has been found that the series arrangement is beneficial along streams needing high removal of algae, BOD, or coliforms. Also multiple cells are advantageous when the loading is seasonal or light, when evaporation or seepage losses are high, or when a new sewer system is being served. All waste stabilization ponds in Kansas, except those considered temporary, are designed with three cell practice.

Kansas experience has demonstrated the necessity of soil sterilization to control weeds where the water is less than two feet deep. An effective sterilant should be resistant to leaching and toxic to weeds, but not to algae.

DuPont weed killers sold under the trade names of "Televar" and "Karmex" have been used extensively with good results.

In designing outlet structures for ponds, provision should be made for varying the water depth, since experience has shown that reducing the depth to less than two feet will speed the recovery of an overloaded anaerobic pond. In the absence of such an arrangement, sodium nitrate has been used successfully to reduce odors during upsets.

Some pond effluents have been observed to have a fairly high BOD due to the high algal population, and while there has been no trouble to date with the oxygen balance in receiving streams some thought has been given to the possible use of the British microstrainer for the removal of algae from pond effluents before discharge to the watercourse in the event that such difficulty should arise.

Creamery Wastes

Kansas has had limited experience in the treatment of creamery wastes along with domestic sewage in stabilization ponds. At Valley Falls, milk and meat packing wastes contribute about 50% of the total load, and the ponds were designed for 18 pounds of 5-day BOD per acre per day. The light loading was used because of the industrial tendency to relase slugs of strong organic wastes and because of the rapid oxygen usage of the milk wastes Some odors have been reported from this installation during spring thaws, but there have been no serious problems because of the isolated pond location.

At Erie, a pond is under construction for treating combined municipal and creamery wastes, with the creamery wastes comprising 60 percent of the total BOD. The loading again is 18 pounds of 5-day BOD per acre per day.

At Council Grove the creamery wastes amount to about 25 percent of the total BOD load. The ponds are sized on the basis of 18 pounds for the creamery load plus an equivalent domestic load, with additional pond capacity for the remaining domestic BOD based on 27 pounds of 5-day BOD per acre per day. This is a new pond and no operating data are available.

None of these three cities permits the discharge of whey into the city sewers or lagoons, and the creameries dispose of the whey separately.

Oil Refinery Wastes

Seven oil refineries in the state have oxidation ponds in use, under construction, or planned. In all cases small concentrated waste streams are stripped of sulfides, ammonia, or phenols before entrance to the plant sewers in order to limit the concentrations of these substances in the main waste stream to 15 ppm sulfides, 15 ppm ammonia, and 7 ppm phenols. All of the refineries provide oil separation as a first step in pretreatment. Beyond this stage, the pretreatment processes vary. In four of the refineries the oil separator effluent flows directly to oxidation ponds. The first pond cell is a small one, which is usually called a skimming pond since additional oil is removed from the water surface in this unit. The total detention time in the oxidation ponds is about 120 days, because of the substantial time required for oxidation of ammonia and lowering of the BOD in refinery wastes.

Three of the refineries employ more extensive pretreatment in order to reduce the size of the ponds required. One refinery plans to use a trickling filter followed by 41 days in oxidation ponds. Another plans to install about 45 minutes of preaeration, chemical precipitation, settling, and to provide 60 days retention in ponds. The third plans to use 5 days of preaeration and oxidation ponds with 60 days retention.

The principal advantages of oxidation ponds over other biological processes for the treatment of refinery wastes appear to be: their great capacity to handle shock loads or slugs, simple maintenance, and the relative ease with which extra storage can be built in for retaining the treated wastes during flows in the receiving stream which are less than the minimum required for dilution of the effluent. One refinery provides sufficient pond area to contain all wastes without discharge of effluent at any time.

Maintenance

The need for daily maintenance of lagoons and oxidation ponds is not as urgent as for conventional types of treatment, but planned maintenance at regular intervals is essential in order to protect the dikes, keep weeds from growing in the shallow water, and to avoid the breeding of mosquitoes or other pests. Weeds and willows will grow in shallow water areas unless controlled by soil sterilization initially, and then by mowing. Broad leafs and willows can be controlled by spraying with herbicides if necessary. Dikes and structures should be inspected regularly for erosion from wind and rain or for burrowing by rodents.

Health Considerations

Waste stabilization ponds offer substantial protection to the public health and compare very favorably with conventional methods of sewage treatment in this respect.

They provide prolonged storage of the wastes, usually for 20 to 90 days, a safeguard not commonly found in other types of sewage treatment. Extensive experience with storage of raw water in water works practice demonstrates that 30 to 90 days storage will reduce coliform organisms by 98 per cent or more. Similar reductions have been observed on a more limited scale in the operation of waste stabilization ponds in Kansas. Pathogenic bacteria are particularly susceptible to destruction by storage.

Conventional treatment processes ordinarily handle the sewage at full strength except for the limited dilution afforded by recirculation when practiced. Stabilization ponds provide immediate dilution of the wastes; the daily dilution being in the order of 20:1 to 90:1. The over-all effect of this great reduction in strength of the waste is beneficial. It avoids the exposure of full strength raw sewage to the atmosphere and reduces the opportunities for contact of pathogens by insects and rodents. Additional protection is afforded since settled sludge is covered by water rather than being exposed as in sludge drying beds.

Less handling of equipment contaminated by sewage is necessary for operators of waste stabilization ponds, thus reducing their exposure.

Summary

To summarize the Kansas experience with waste stabilization ponds, they have been successfully applied to the treatment of domestic and certain industrial wastes. They are especially suited to handling the wastes from small communities. Maintenance is minimal but essential. Waste stabilization ponds provide as much public health protection as conventional treatment methods. No more nuisance, and perhaps less, occurs with this type of treatment than with convention methods. The cost of ponds for cities smaller than 3,000 in population is less than the cost of conventional treatment. However, the difference is not sufficiently great to preclude the use of conventional facilities on a cost basis under many conditions, and both types should be considered in solving the treatment problems of small communities.

The design of waste stabilization ponds is dependent on characteristics of the sewage flow, rainfall, evaporation, seepage, topography, and soil conditions. While the structural design is not complicated, a basic understanding of the biological and chemical processes is essential to a successful design.

As more operating experience is gained, as new knowledge is produced by research, and as information is exchanged at forums such as this, it should become possible to delineate more precisely the design criteria for waste stabilization ponds and to understand more fully the fundamental processes involved.

WASTE STABILIZATION LAGOONS IN MISSOURI

by

Jack K. Smith[*]

Probably the first sewage lagoon in Missouri was constructed at Potosi about 18 or 19 years ago. This lagoon was preceded by a septic tank. The septic tank was not properly maintained and removed only a portion of the objectionable material in the city sewage.

The lagoon which was constructed about 1500 feet below the septic tank served to reduce the pollutional load to the stream. By modern standards the lagoon was not properly constructed, but it did reduce the organic load of the partially treated sewage. Mr. A. R. Baron, Division of Health District Public Health Engineer, noted the effectiveness of the treatment works and suggested that properly designed and constructed lagoons might afford adequate treatment.

In 1952, a large open septic tank 65 feet wide by 150 feet long and 5 feet deep was placed in operation at Ruskin Heights, Jackson County, to serve as a temporary sewage treatment device until a modern trickling-filter type plant could be completed. The open septic tank operated as a lagoon, producing a stable effluent without objectionable odors.

At Warsaw, a natural lagoon was created when the water level in the Lake of the Ozarks dropped. The original lagoon was very shallow, less than two feet deep. However, homes in the immediate vicinity reported no odors.

For the period of 1953 to June 30, 1960, 247 lagoons serving municipalities, resorts, motels, schools, subdivisions, slaughter houses, poultry processing plants, milk plants and automatic laundries have been constructed and placed in operation in Missouri. There are numerous other installations throughout the state including those at private residences that we do not have data on. The 247 lagoons presently in operation are designed to treat wastes from 301,228 persons.

In 1958 we made a study of the costs of municipal lagoons and included a land cost of $300 per acre with a lagoon site requiring at least 1 1/2 times the water surface area. We arrived at a per capita cost of $9.84. At the same time we computed the average per capita cost of mechanical plants and found that to be $41.58. The difference in per capita cost is $31.74. This difference times the population equivalent served by the lagoons represents a savings in first cost of $9,560,977. We estimate that the annual operating cost of lagoons is less than one tenth the operational cost of mechanical plants.

Lagoon sizes vary from the individual size of 800 square feet water surface area to municipal installations with a water surface area of 50 acres. The largest waste stabilization lagoon system is now under construction at Poplar Bluff, Missouri, with a design population of 29,200 and a total lagoon water surface are of 146 acres.

As of July 1, 1960, the municipal lagoon census in Missouri was as follows:

Cities Using Waste Stabilization Lagoons for Sewage Treatment	45
Cities Where Waste Stabilization Lagoons Are Under Construction	18
Cities Where Waste Stabilization Lagoons Are Proposed	46

Municipal lagoons are designed on the basis of 34 pounds B.O.D. per acre.

---

[*] Executive Secretary, Missouri Water Pollution Board

The various uses for waste stabilization lagoons in Missouri are as follows:

In the metropolitan areas of Kansas City, Missouri, St. Louis, Columbia and Mexico, waste stabilization lagoons have been used for interim treatment pending completion of trunk sewers and permanent treatment works. The design loadings are 400 persons per acre.

Some odor problems have developed in the winter months. These odor problems can be adequately handled by the addition of sodium nitrate applied in the inlet pipe or around the edges of the lagoon at the rate of one pound of sodium nitrate per pound of B.O.D.

Near Wright City, Missouri, the Wright City Meat Company in 1956 constructed a waste stabilization lagoon for the treatment of the wastes arising from slaughtering and meat processing of hogs and beef. The average kill of hogs is 8 to 20 per week. The average kill of beef is 4 to 8 per week. The slaughter house is served by a private well that is metered; the average weekly water pumpage for all purposes is approximately 4,000 gallons. The lagoon has a water surface area of 100 feet by 250 feet at the 3-foot depth; to date there has been no overflow. The water level has been stabilized at approximately 2 1/2 feet. Based on present design criteria for slaughtering and processing establishments of 400 population equivalent per acre of water surface area, this lagoon is approximately twice the area deemed necessary. It should be pointed out that the Wright City Meat Company does not save the blood. The lagoon is located within 150 feet of the slaughtering and processing establishment; there have been no odor problems or nuisance conditions to our knowledge. The Wright City Meat Company is a drive-in retail establishment and odors and nuisance conditions would, of course, be very detrimental.

Waste stabilization lagoons have been used for treating the wastes from poultry processing plants. At Cabool, Missouri, a waste stabilization lagoon with a water surface area of 7 1/2 acres was placed in operation in November, 1958. The design basis was 34 pounds B.O.D. per acre. In July of this year the plant was processing 10,000 chickens per day and the water usage was 260,000 gallons over a 12-hour period. In the design of the waste stabilization lagoon the consulting engineers designated a sewage flow of 150,000 gallons per day. The waste stabilization lagoon is constructed near the municipal sewage treatment plant. It was proposed to pump the supernatant from the digesters to the lagoon; however, until recently the city was pumping all of the raw sludge from their treatment plant to the lagoon. The sewage treatment plant is designed to serve 1,750 persons.

At Noel, Missouri, a chicken processing plant is served by a 20.2-acre waste stabilization lagoon. The design basis is 34 pounds B.O.D. per acre. This lagoon was placed in operation in January of this year. It is anticipated that the plant will process 44,000 chickens per an 8-hour day. Present production at the plant is in the 30,000 to 40,000 chickens per eight hours.

At Purdy, Missouri, a waste stabilization lagoon with a water surface area of 8,000 square feet at the 3-foot depth was placed in operation in November, 1959. This lagoon is designed to treat the wastes from an automatic laundry with ten machines and one toilet. The anticipated sewage flow is 2,020 gallons per day. To date this lagoon has operated quite satisfactorily. A previous lagoon installation serving a coin-operated laundry at Eldon, Missouri, which was in operation for a period of about three years has now been abandoned. This operation was considered satisfactory.

Several public schools constructed through the reorganizational program for rural schools have built waste stabilization lagoons. These lagoons are designed on the basis of 800 persons per acre. Where ground garbage is discharged into the sewer system the lagoon area is increased 30%. Actual sewage flow data is not available for these school installations. We have observed that there is very little, if any, overflow from these lagoons. During the last three to four years rainfall has been near normal and evaporation has not been excessive. During the summer months when schools are not in use the water level in the lagoons is lowered six to eight inches.

Organizational camps such as the Windemere Baptist Assembly, Roach, Missouri, Camden County, utilizes a waste stabilization lagoon for sewage treatment. The camp is used only during the summer months. The lagoon design basis is 200 persons per acre. This installation has been entirely satisfactory.

Lagoons are in use at Aurora, Missouri, following primary sedimentation, trickling filter and sludge filter installations. Two lagoons are provided, one with a water surface area of 3.3 acres and the other with a water surface area of 4.6 acres. Each lagoon is designed on the basis of 67 pounds B.O.D. per acre. Actual operating results are not available but visual inspection reveals a satisfactory effluent.

At Monett, Missouri, a 4.59-acre waste stabilization lagoon has been constructed following a standard rate trickling filter plant with final settling. The design load on this lagoon is 31 pounds B.O.D. per acre. Laboratory results are not available but visual inspection reveals satisfactory stream conditions.

Waste stabilization lagoons have been used satisfactorily for treating the wastes from a creamery at Emma, Missouri. This creamery constructed three lagoons with a total water surface area of 2.95 acres and a water depth of five feet in 1955 to treat milk waste. The following results have been recorded:

1. Date October 18, 1955
Total Flow, Inlet = 11,700 gallons
B.O.D. -Raw Waste = 1192 ppm
B.O.D. -Raw Waste = 116 pounds
B.O.D. -applied = 39.3 pounds per acre
B.O.D. of effluent = 112 ppm.
Reduction of B.O.D. = 90.5% assuming outflow equals the inflow

2. July 19, 1956
Total Flow, Inlet = 14,550 gallons
Total Flow, Outlet = 8,500 gallons
B.O.D. -Raw Waste = 2,700 ppm.
B.O.D. -Raw Waste = 327.2 pounds
B.O.D. -applied = 110.9 pounds per acre
B.O.D. of effluent = 54 ppm. or 3.8 pounds
Reduction of B.O.D. = 98.8%

In the spring of 1956, septic conditions accompanied by odors developed. At this time the milk plant was receiving over twice the average volume of milk and cream. One hundred pounds of sodium nitrate per day was added until the lagoons were again aerobic, a period of about one week. Since that time 400-500 pounds of sodium nitrate per week have been added.

Recently, the Adams Dairy near Blue Springs, Missouri, constructed two waste stabilization lagoons, one with a water surface area of 5.25 acres and the other with a water surface area of 5.28 acres; the total water surface area being 10.53 acres. The design basis for the lagoon was 45 pounds B. O. D. per acre. A composite sample of the raw wastes collected on April 27, 1960, showed that the B. O. D. was 1130 ppm., and the total sewage flow was 60,000 gallons for the 24-hour period. The total pounds of B. O. D. to the lagoon amounted to 568 or 53.7 pounds of B. O. D. per acre. The lagoon was placed in operation in March, 1960. The operation of this installation is considered to be satisfactory.

One of the first municipal lagoons in Missouri was in Montgomery City. Several surveys have been made of this lagoon and the following information obtained:

Dissolved oxygen in the Montgomery City lagoon varies from 4 to 17.6 ppm. B.O.D. of effluent = 17 ppm. M.P.N. of effluent = 460 per ml. This lagoon has a water surface area of 12.4 acres, a depth of four feet and treats the waste from about 1500 persons. A recirculation pump (85 gpm.) is provided which returns to the inlet pipe a volume approximately equal to the total average daily sewage flow. The pump is designed to take suction from any depth in the lagoon. It would appear that the pump is responsible for a greater variety of plankton and possibly a higher dissolved oxygen content in the lagoon. Insufficient data have been collected to determine the advantage of recirculation.

Operational problems with waste stabilization lagoons in Missouri have been minimum. Some municipal lagoons have experienced odor difficulties in the spring following a severe winter. These odor complaints can be satisfactorily handled by the addition of sodium nitrate applied at the rate of one pound of sodium nitrate per pound of B.O.D. There have also been some problems with blue-green algae in the summer months. It is our opinion that the blue-green algae problem can be satisfactorily handled by the addition of Phygon applied at the rate of 1 ppm. in the lagoon influent and around the water edges. We also believe that breaking up the algal mats by the use of an outboard motor or pumping equipment will satisfactorily handle the blue-green algae problem.

Cattails have posed a problem in some municipal lagoons. The best solution to this problem is actual removal of the plants. At Perry, Missouri, there was a small growth of cattails in the city's lagoon; however, muskrats solved the problem by harvesting all of the cattails. The city then requested the Conservation Commission agent to trap the muskrats.

The proper maintenance of the turf is a problem; however, the city of Hornersville, Missouri, has a unique solution to this problem. Hornersville, a city of 875 (1950 population), in southeast Missouri has a waste stabilization lagoon with a water surface area of 7.5 acres. The turfed dike area is approximately six acres. The dikes were seeded with Burmuda grass. In addition to the lagoon site, the city owns an additional fourteen-acre tract adjoining the lagoon. The maintenance of the turf is provided by eight cows and a bull. In extreme dry weather the 14 acres are used to pasture the cattle. The cattle drink the lagoon water. The city reports that the first year's calves paid for the cows. The mayor also reports that the lagoon is stocked with several species of fish. Soon after the lagoon was completed in 1956 the dikes were topped ;by an unusual flood. The city officials state this flood was responsible for stocking the lagoon with fish.

OBSERVATIONS OF WASTE STABILIZATION LAGOONS IN NEBRASKA

by

T. A. Filipi*

In observing the operation of the 41 lagoons in Nebraska they would all be perfect if it were not for:

Inadequate preliminary study,
Inadequate and improper design,
Faulty construction, and
Lack of operation.

The waste stabilization lagoon in my opinion has been one of the greatest contributions to sewage disposal that has come forth within the last several years. I regret very much that we did not boast of the operation of the Alliance, Nebraska lagoon which has been in operation for over 30 years. When representatives of the Air Force observed the operation of this lagoon during the war they could not understand how the lagoon could take the overload with no undesirable effects. Consequently, a team of scientists was assigned to study the operation and all of the claims that were made for the lagoon were justified. We, however, failed to make this operation known. Consequently, other states are now boasting of the age of their lagoon operations, but I go on record that our lagoons have operated successfully long before the lagoon was even considered.

In the main the results of operations of our sewage stabilization lagoons are satisfactory, and there are no complaints from persons living in the vicinity of the lagoons

The lagoon has been responsible for the construction of sewage disposal systems in many a Nebraska municipality because it permitted the entire construction to be made at a cost which the community could assume. In most cases the cost of the disposal of wastes by the lagoon method is approximately 1/3 to 1/2 that of the conventional plant. Furthermore, there are many communities in our State which have no stream for dilution and dependence has to be made upon soil absorption and upon evaporation. In checking over the possible sewer systems for Nebraska it appears that from now on all sewers that are constructed are in a class and in a location where the lagoon should be seriously considered as a means of disposal.

Due to one sided publicity, engineers and municipal officials are assuming that the lagoon is a panacea for all waste disposal. Therefore, sufficient study is not being given to the overall problem at hand and frequently no thought is given to other means of treatment. In the general sanitation program it is our opinion that there is still a large field for construction of conventional plants and that a conclusion that the lagoon will be used before any study is made is erroneous. For some reason or other the lagoon has received such publicity that frequently when conferring with a Board of Trustees or attending town meeting for the promotion of a sewer system the entire discussion centers around a lagoon. The sewerage system decision rests upon ability to use a lagoon. From the standpoint of a Department of Health we are most interested in overall sanitation and do not desire that the lagoon should be of prime discussion when sewerage is discussed. Let us give more consideration to the publicity that is promulgated on this subject.

Inasmuch as a lagoon appears to be a very simple structure in most cases engineers working in Nebraska do not give sufficient attention to preliminary studies. Entirely too many assumptions are being made as to the quantity of sewage, the strength of sewage, it characteristics, chemical analysis of the waters and other details. There are four lagoons in Nebraska that at the present time are so dry that a person can walk across the entire structure. Our Department has not determined whether it is the lack of sewage or the improper soil preparation of the floor of the lagoon that is the culprit. However, more preliminary studies would have corrected the situation. It is regreted that in the course of sanitary engineering given in schools and colleges 30 years ago the design criteria of lagoons was not offered. Therefore, there is much to be desired in the design of the lagoon in all of its details, the inlet, the splash plate, the location of the inlet, the number of cells, control structure, overflow structures, soil mechanics of the lagoon floor and the dikes of the units when finished. Undoubtedly, the engineers of Nebraska are quite frustrated because of the amount of literature that is being sent to them on the subject from the Health Department much of which is in contradiction with a previous directive. Yet, there is no new principle in the lagoon that is not enveloped in some of the basic courses taken by an engineer either in college or could be read through current literature. However, I believe that the design of lagoons is sadly overlooked because of erroneous ideas.

---

*Director Division of Sanitation Department of Health Lincoln, Nebraska.

In the area of design we cannot over emphasize the need of more study being given to the soil. We are now convinced that a complete soil survey should be made of the lagoon site, samples taken, analyzed by a reputable laboratory and formulation for the various areas made up to insure the specific quality of soil needed for the specific purpose. This then will insure proper water holding characteristics, prevention of soil bank erosion, and proper seeding of desired areas. The mere compaction to 90% Proctor density is not sufficient to give the desired results. Futhermore, tests should be made on the finished structure and adjustment's made if necessary. Specifications will have to be altered to permit the performance test to be the governing characteristics rather than the mere matter of construction.

Due to the fact that the lagoon is so simple a structure, has no pumps, motors, air compressers, aerators, and other equipment the municipal officials are prone to neglect hiring of proper personnel and giving them sufficient time to properly maintain a lagoon. At the present time in discussing the lagoon with persons intending to install one we state that a lagoon operator should be as qualified an individual as one operating a conventional plant. In a conventional plant the operator can control his environment. That is, he can increase the speed of the air compressors, he can change the flow from tank to tank, he can increase or decrease his suspended solids, can vary the alkalinity, or acidity of any process and in short control the various phases in the plant. In a lagoon the operator must obey nature and first learn nature's laws and then co-operate. It is very much similar to the operating of a sail boat versus a power boat. In general the design and construction criteria could be overcome if good operation was insured. Here again, a plea is made to the engineers and possibly the publicity and promotional people of popular magazines to stress the need of operation rather than stress the simplicity requiring no attention. Furthermore, stress should be given to preventive maintenance. At the present time we have several lagoons in Nebraska where erosion has cut the banks to forming ravines 30 inches deep. If the operator was interested in his assignment and would have visited this lagoon daily as is our instruction this ravine could have been corrected with perhaps one or two shovels of dirt and a hand full of seed by avoiding the terrific job rebuilding the entire dike. If the operator would have pulled out the willow on the bank of the lagoon while a sapling it would have avoided cutting down a tree with a power saw. If weeds that are emerging just off the shore line were pulled it would have prevented their spreading into the lagoon and making necessary removal by means of a barge or boat. We cannot emphasize too greatly the need of simple daily consistent maintenance and operation.

We are insisting that lagoons be placed one half mile from town and a quarter of a mile from the closest inhabitant. Therefore, even though our personnel have found lagoons that are infested with mosquitoes, have an odor, have eroded dikes, have a growth of trees along the shore line and many other items which are against general lagoon operating principles we still do not have a growth of trees along the shore line and therefore, take the stand that the lagoon will be placed far enough away from town and be left to deteriorate as is possible and not worry the municipal officials and especially the operator of proper maintenance.

Jealously we have been endeavoring to have lagoon maintenance of such type so that when municipal officials of communities planning lagoons would visit them they would go away enthusiastic about the structure. I regret that time did not permit to show photographs of some of the lagoons that we have which will I am sure unsell any prospect. Yet, when these people discuss the lagoon with municipal officials they are assured that in spite of the mosquitoes, the weeds, the trees, the erosion and odor that the lagoon is far enough from town that no one seems to complain.

Another observation that appears to be common with all lagoons is that of estimating future growth. It is our opinion that a lagoon should be constructed for the immediate load and that only. We are finding that lagoons that are constructed and not used, deteriorate to such degree that if they ever will have to be used the entire structure will have to be rebuilt. We would, therefore, suggest to municipal officials that a lagoon is a cheap means of disposing of sewage and that they construct that facility that they need at the present time with the understanding that when the original structure is overloaded that another cell will be constructed. Working with municipal officials in this matter, is of course, difficult because by the time the first unit is loaded another Council is in power and just cannot see why at the end of 5 to 6 years the facility is over loaded and needs expansion. They completely forget about the arrangements and agreements that were made even though in writing.

The lagoon in our opinion is serving a useful purpose in disposing of domestic and industrial wastes and has been responsible for much sewerage installation and for much abatement of pollution of our streams. However, it is our opinion that the lagoon at the present time is on too low a level of engineering status and perhaps too low on the operational level of municipal utilities. Consequently, it is not receiving the serious attention in the design, construction and operation. If we can elevate the status of lagoons to that of a trickling filter plant, an activated sludge plant, or perhaps chemical recipitation giving it serious consideration in all details I am sure that more lagoons will be constructed and the operation phases of all details will be satisfactory to not only the stream pollution control authorities, but to the Health Department officials and to the persons in close proximity of these lagoons.

SUMMARY OF THE OPERATIONAL HISTORY OF RAW SEWAGE LAGOONS IN THE STATE OF COLORADO

by Ronald C. McLaughlin*

One approach to one establishment of design criteria for the construction of new sewage stabilization ponds, is to evaluate the operation of existing functioning ponds. In attempting this, we relied mostly on the opinion of the Department's District Engineers who service the particular areas and have the closest personal contact with the individual facilities. Using the interpretation of several engineers naturally may lead to variation of results, but this was minimized by defining the physical characteristics as closely as possible and by reviewing individual attitudes.

Many variables other than loading e.g. pond shape, operational control, climatological differences (considerable due to the altitude changes in Colorado), waste characteristics, etc., undoubtedly have effected the comparative operation of these lagoons. It was hoped that a study of the histories of a sufficient number of ponds would show a pattern even though large data variances were present.

A list of communities with individual figures used is shown in Table 34. Operational information only, on 25 ponds in the State of Colorado was used in the analysis. Our Design Standards call for a water depth of between 3 and 5 feet and all of these ponds are so designed.

A plot of loading versus operation history classification is shown on Graph A.

Interpretations made from Graph A must be thought of as approximate and considered only as observations of limited data. The following observations were made:

1. 60% of the ponds in Colorado are operating in a loading range of 100-200 persons per acre.
2. Of the ponds that are operating at 100 or less persons per acre, loading 100% (4 out of 4) were classified as good or excellent.
3. Of the ponds operating at a loading from 101 through 200 persons per acre, 86% (12 of 14) were classified as good or excellent. 14% (2 of 14) were classified as fair or worse.
4. Of the ponds operating at a loading above 200 persons per acre, 29% (2 of 7) were classified as good or excellent. 71% (5 of 7) were classified as fair or worse.
5. Without having made a specific study of a conventional type plant, it is known that ponds as a method of treatment would have a much better average operational history classification than the conventional plant facilities in Colorado.

See following page for:
(Table 34, SUMMARY OF THE OPERATIONAL HISTORY OF RAW SEWAGE LAGOONS IN THE STATE OF COLORADO)

---

*Division of Sanitation, State Department of Public Health.

TABLE 34

Summary of the Operational History of Raw Sewage Lagoons in the State of Colorado

COMMUNITY	Est. Tributary Population Equiv.	Area Acres	Loading Pop/Acre	General Classification of Operation*
Alamosa................	5,400	47	115	Good
Altura.................	3,500*	20	175*	Poor
Buena..................	700	4.2	165	Good
Burlington Sanitation District............	400	2.0	200	Excellent
Byers..................	250	2.5	100	Good-(2-2 1/2 acre ponds) 1-pond in operation 1/2 of town is hooked on.
Calhan.................	350	1.35	260	Fair
Carbondale.............	450	3.0	150	Good
Clifton................	430	1.92	225	Good
Colo. Training School for Girls-Morrison..	150	0.5	300	Poor
Craig..................	4,500	27	165	Fair
Del Norte..............	1,200	14.3	85	Excellent
Dove Creek.............	1,300	6.1	213	Good
Erie...................	780	3.4	220	?
Erie Series Operation...............	780	1.75	450	Poor
Fountain...............	1,200	3.1	390	Poor to fair
Fowler.................	1,200	6	200	Good (except when slaughterhouse was connected)
Frederick (Tri-Area)...	1,200	8.3	145	Good-excellent
Keenesburg.............	325	4.5	75	Good
Kremmling..............	800	6	133	Good
Lamar..................	10,000	96.6	103	Excellent
Monte Vista............	3,600	32.9 or 27.1	110	Good
Norwood................	400	2.0	200	Excellent
Nucla..................	500	1.0	500	Fair-expansion in 1960
Widefield Homes........	100	5	20	Excellent
Wray...................	2,400	12.3	195	Good
Yuma...................	1,800	9.0	200	Good
Totals-Average......	42,935	325.97	Ave. = 132	Ave. = Good

*Pond Operation Classifications

Choose the classification most nearly describing the ponds.

FAIR - Almost continuously anaerobic with odor nuisance and/or health hazard.
No D.O. in effluent.
Effluent not complying with state standards - BOD greater than 50 ppm.

POOR - Frequently anaerobic with odor nuisance and/or health hazard.
Effluent does not comply with 30 ppm.
BOD concentration standard.

FAIR - Anaerobic occasionally (more than 1 or 2 weeks per year) with some odor complaints.
Effluent normally expected to meet standards with exception of coliform MPN.

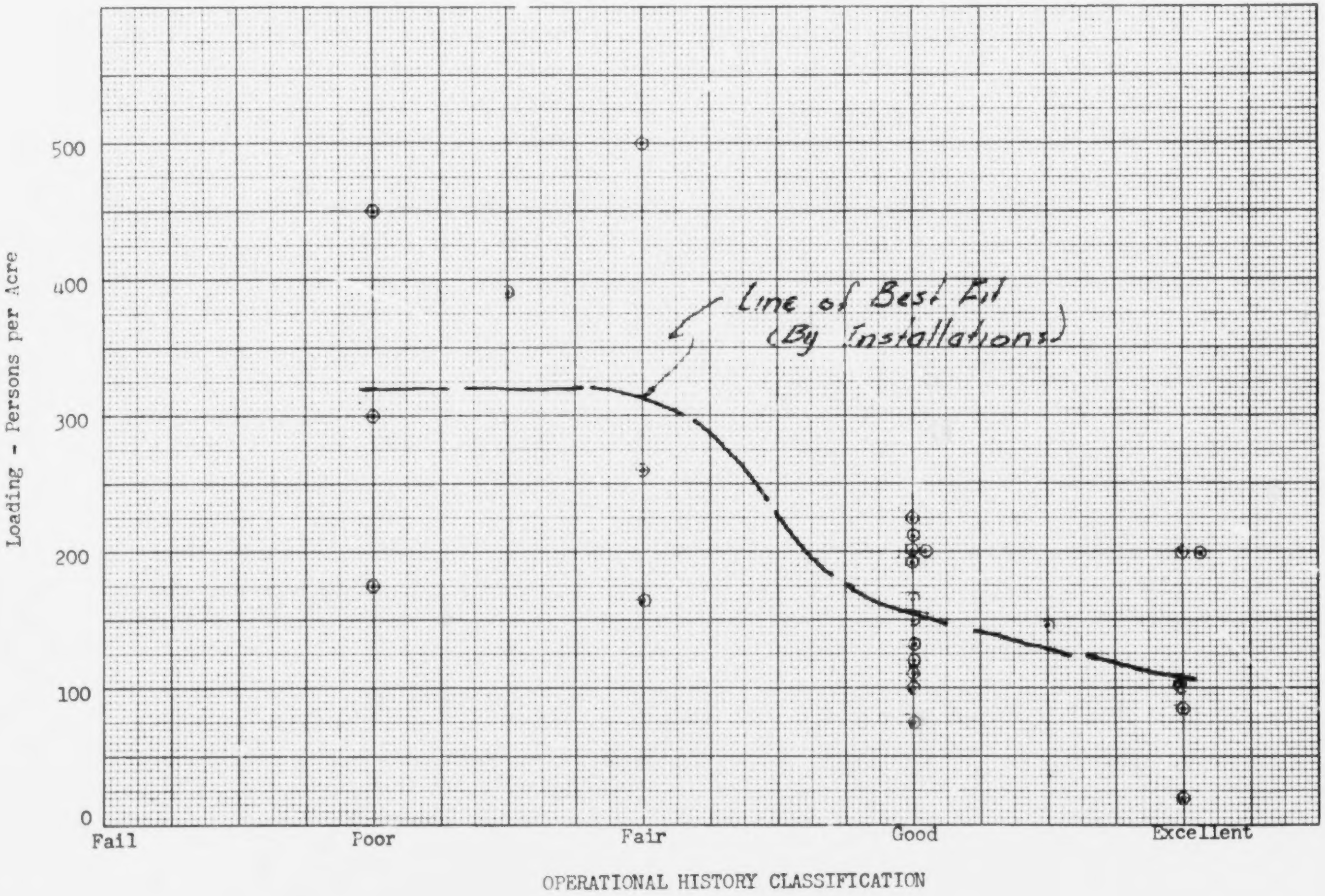
GOOD - Only anaerobic for short period in Spring.
Effluent expected to meet state standards.
Evidence of good biological growth continually.

EXCELLENT - No record of odor complaints (aerobic operation).
Effluent, if any, meets state standards.
Always good biological growth in ponds.

NO. 3210. 20 DIVISIONS PER INCH BOTH WAYS. 120 BY 180 DIVISIONS. CODEX BOOK COMPANY, INC. NORWOOD, MASSACHUSETTS

GRAPH A

SUMMARY OF THE OPERATIONAL HISTORY OF RAW SEWAGE LAGOONS in the State of Colorado



EXPERIENCE IN WYOMING WITH WASTE STABILIZATION LAGOONS

by

David P. Green*

The waste stabilization lagoon is an accepted method in Wyoming, for the treatment of both industrial and domestic wastes. These units are considered to produce a degree of treatment equivalent to the conventionally accepted methods of secondary treatment.

The following discussion will treat the subject first in terms of factors required by climate, terrain and other natural conditions; secondly will deal with a few recommended design considerations which experience has indicated to be desirable; and thirdly, by a brief discussion of experience, both favorable and unfavorable, with such lagoons in Wyoming in the recent past.

Wyoming, for the most part, is an arid state, having extremes in temperature. Freezing conditions and snow may be expected from October to late April, although long periods of intense sunshine are common and mitigate the often severe winter conditions. As might be expected, the low humidity and intense sunlight, coupled with relatively high wind velocities, result in high rates of evaporation.

Both industry and municipalities are, for the most part, concentrated in the river valleys, such as those of the North Platte, Green and Big Horn Rivers. The river valleys are generally narrow and boarded by desert; or at least near desert country. It will be realized that this type of topography, together with the sparse population, has made the waste stabilization lagoon a preferential method of treatment. This is shown by the pollution abatement program which has resulted in the construction of 46 municipal lagoons since 1955, while only 4 conventional plants have been built during the same period. Acceptance of the waste stabilization lagoon has been even more marked with industry private corporation.

The Wyoming design criteria for lagoons generally follow those suggested by the Missouri Basin Engineering Health Council. Allowable BOD loadings for raw sewage lagoons are shown as a population equivalent of 200 persons per acre (35 lbs. per acre). Thus far, theoretical consideration has shown no necessity for the development of specific criteria for retention or hydraulic loading for conventional organic wastes where the stabilization of the oxygen demand and reduction of bacterial population are desired.

Design practice calls for operation at two depths, 3 feet during the summer and 5 feet during the winter months. These are primarily an empirical pair of values. The lesser depth is based partially on experience in preventing the growth of rooted aquatics providing circulation and partially on some studies conducted several years ago concerning light transmission thru algae bearing waters. The winter depth is almost solely empirical and represents an attempt to compromise the recognized effect of temperature on the reaction velocity constant for "anaerobic" or heterogeneous conditions brought about by the "Blackout" of solar energy due to ice and snow cover, as against the increased cost of construction if a specific high degree of treatment were to be mandatory.

Several very limited investigations have been made of the location of inlets and outlets There seems to be a definate indication that, at least in small units, i. e. under 10 acres, an effect is exerted by prevailing high winds causing some short circuiting. The data are insufficient for conclusion to be drawn, but it is suggested that consideration might be given to these factors of wind direction and velocity.

---

*State Department of Public Health Sanitary Engineer

The location of population centers in river valleys has led to the problem of sealing lagoon bottoms in many cases. Originally a literature search was made, however, it was felt that the majority of the work, having been done on irrigation canals, was not applicable to lagoons since velocity conditions, etc. are not encountered.

Several methods of sealing have been used in Wyoming, and all are apparently equally sucessful, the choice being economic. These are the installation of a 4-inch true clay blanket, the use of a seal coat of crude bentonite worked into the surface of the bottom, and by asphaltic soil stabilization. In the last case, an MC-oil or RC-oil has been applied by distributor for a total application of 0.5 to 0.7 gallons per square yard. Interior banks are treated either by hand hose or an adapted spray bar.

Since the pollution of shallow ground water does not constitute a problem, in Wyoming, it is our opinion that the seal must be effective for a period of 6 to 12 months, after which we believe that accumulated algae and sewage solids will effectively plug the soil interstices forming the equivalent of an impermeable membrane.

The great majority of lagoons in Wyoming are of the multi-cell flow thru type with piping arrangements for either series or parallel operation. Although a few complete retention lagoons have been designed for areas where either no defined drainage exists or for specific industrial problems where a discharge could not be tolerated. Despite calculation these units may have to be enlarged as experience dictates.

More recently variations have come into limited use, as for example at the Jeffrey City Townsite of the Western Nuclear Company. In this case the units are slightly modified and field irrigation effectively supplements the lagoons.

Recently it came to our attention that operating difficulties were being experienced in multi-cell units. Our investigations indicated that these units were not being loaded on the basis of surface area. Therefore we now require that all multi-cell units be provided with some type of flow measuring device on the inlet. Flow measuring devices on outlets might also be considered where such information might be of value in material balances. I would like to add that, in my opinion, series operation during our long cold weather period, would tend to increase benthal loads unduly in the spring.

Another item which is too frequently overlooked is that of composition of the wastes. A simple example of this is the use of lagoons for secondary or tertiary treatment after some type of pretreatment. We have found, for example, that small lagoons are valuable following septic tanks at trailer courts, or after sedimentation in several small towns. In these cases it must be realized that the criteria should reflect the removal of the nonsoluable BOD, and therefore that the units can logically be smaller.

Many industrial wastes will require some type of pre-treatment, although lagoons can and do adapt to a surprising degree. Studies must be made of the composition of the waste, the sources for specific components, the effect and reliability of the methods of pre-treatment, the effect or normal and possible shock loads on the lagoon and finally the compatibility of the waste to the lagoon method of treatment and the degree of stabilization expected under varying conditions. A few examples of pre-treatment are as follows:

1. Packing House Wastes: All possible blood, paunch manure and solids must be retained in the plant. This is not a new waste and recognized methods have been developed for proper in plant housekeeping. Failure to carry out such a program would not only require an inordinately large lagoon system, but would result in the formation of floating scum mats and possible effective blackout of the pond due to coloration. These, of course, create nuisance conditions as well as generally result in an unstabilized effluent.
2. Petroleum Wastes: Toxic substances and oil must be reduced to the practical minimum prior to discharge to a lagoon. Where possible total retention systems or adaptations of those systems should be used.
3. Wool Scouring Wastes: Recently the Wyoming Department of Public Health

was required to evaluate waste stabilization lagoons as a possible method of treating this type of waste. A literature search and chemical analysis determined that this waste, had an extremely high BOD, oil and grease, and solids content. The problem was further complicated by the use of a very high concentration of an industrial non-ionic detergent. Consideration of all possible methods of pre-treatment did not indicate that the waste load, particularly the detergent, component, could be treated by the lagoon method, to say nothing of providing a satisfactory effluent.

It is believed that the remainder of this discussion could best be devoted to a discussion of specific problems encountered within the last three years. I would like to point out that the laboratory facilities of the Wyoming Department of Public Health is extremely limited and that only a bare minimum of the data considered desirable has been obtained.

Various difficulties have been experienced with municipal waste systems. Illustrating examples are as follow:

1. In the first case: This particular unit had been designed as a one cell flow thru unit based on 17 lbs. of BOD per acre, and operable at both 3 and 5 foot water depth. The unit had a record of completely satisfactory operation for two years. The lagoon failed going into anerobic condition suddenly. Insofar as was known, no industrial wastes had been recently accepted into the system, nor had there been any great increase in population served. A small amount of oil was noted on the leeward end of the unit, but the Town had an enforced regulation against discharge of waste oil to the sewers.

   Eventually a leak was discovered in a short section of crude oil pipeline passing near the lagoon.

   Sufficient oil had been discharged to the unit to create a toxic condition, without causing large areas of oil on the surface. Practice now requires that such lines are relocated.

2. The 2nd case: It concerned a one cell flow thru unit designed on the basis of 35 lbs. of BOD per acre and capable of operation at 3 and 5 foot water depth. During the late summer of 1958 an inspection found that the lagoon had failed. The lagoon water was found to be a deep red and approximately 1/8 of the surface was covered by a floating scum mat. As previously, the northern series pair showed aerobic or probably truly facultive conditions with the degree of treatment increasing from interior to exterior cells. An overall BOD reduction of 82% was achieved by aerobic conditions under an average of 50% ice cover at water temperatures just above freezing.

   The Southern pair was found to be "Anaerobic" - or at least lacking in dissolved oxygen as determined by standard analysis. Algae were present, however, in lesser numbers than in the other pair, but in sufficient quantity to indicate a heterogeneous type of stabilization. H_2S generation was marked. Although the overall BOD removal was 78% with this pair, the degree of removal lessened as flow progressed from interior to exterior cells. It had been found in the study that sewage flow was split to the lagoons on some basis other than loading per surface acre. Apparently this incorrect distribution over a period of time among the cells produced sufficient benthal decomposition due to temperature effects on the rate constants to cause this situation to occur.

On the whole, few difficulties have been experienced with industrial waste stabilization lagoons. I belive that others have have discussed a majority of industrial waste problems, therefore only two examples are presented.

1. Standard Oil Company, Casper: This is a large full line refinery. All wastes after oil reclamation and housekeeping procedures are discharged to a large retention area. Phenols seem to be almost totally removed and treatment appears to be excellent. No ground water problems

are encountered and no return water is discharged to the North Platte River, but is disposed of by evaporation and percolation.

2. Western Nuclear Corporation, Jeffrey City: This plant processes uranium ore under AEC license. A total retention lagoon has been constructed for mill wastes which would otherwise be discharged to the Sweetwater River, causing radio-nucleide chemical and physical pollution.

   Investigation found that a packing house had been given sewerage service several days previously and that no pretreatment had been required. Although the packing house was small, the discharge of raw waste had raised the influent BOD loading on the lagoon to nearly 100 lbs. per acre. This of course was corrected by pre-treatment, but it is interesting to note that the lagoon was anaerobic only at night; the aerobic-anaerobic cycle lagging the day-night cycle by approximately 2 hours.

3. The 3rd example concerns a 4 cell unit serving approximately 18,000 people and designed on the basis of 30 lbs. of BOD per acre. The flow arrangement in this particular unit is unusual. Raw sewage is loaded into all cells. Two interior cells then over flow into the remaining two exterior cells. The only unusual industrial waste is a small wool scouring pilot plant operated on an extremely limited basis for 2 months during the summer. This system has been found to have anaerobic conditions in 1 series pair and aerobic conditions in the other in the spring of 1959. Although surface effluent discharge is provided, this could not account for variations within the unit.

   Since this is the largest unit in the state and good laboratory and technical facilities are readily available a study was planned for 1960. The study would include BOD, DO, Nitrogen series, phosphate, oil and grease, detergent analysis and biological and bacteriological work. The first sampling series was planned for the spring ice-break-up in 1960.

   The unit is radiologically monitored and is well below the accepted exposure values. No significant change is found in radioactivity or in nitrates in the ground water.

In summary I wish to present the underlying ideas of the proceedings: that a rationale should be developed for the use in the design of waste stabilization lagoons for specific situations and furthermore that the lagoons are merely another type of treatment which may be preferable in a specific situation.

ARCTIC SEWAGE LAGOONS

by

Charles F. Walters*

The Arctic Health Research Center has been observing two experimental sewage lagoons in Alaska for the past three years. Design recommendations of the Center engineering staff were followed by consulting engineers in the preparation of plans for both installations. Under AHRC sponsorship the Alaska Department of Health approved the lagoons on an experimental basis to permit observation of the effects of extreme climatic conditions, including long periods of thick ice cover.

One of the lagoons, located at Sutton, Alaska (60 miles from Anchorage), was designed for a population of 50 persons from a roadhouse and adjacent trailer court. The area of the unit, based on a loading of 200 people/acre, is 1/4 acre. The normal summer operating depth is 3 feet, however, provisions was made for a winter storage to a depth of 5 feet.

The lagoon did not hold liquid during the first two years of operation despite several attempts to seal the bottom. Silt from a nearby stream was diverted to the lagoon but subsequent retentions lasted for only a month, after which time the lagoon would again empty. Although there was an accumulation of sludge around the center inlet, no odors were detected.

The other experimental lagoon, located at Ft. Yukon, Alaska (150 miles north of Fairbanks) was designed for an elementary school serving 200 non-boarding children and 8 adult teachers.

A 1,100 foot, 6 inch, wood stave pipe carried the sewage from a sump in the schoolhouse to the inlet structure in the middle of the 125 foot square area. Although an overflow was provided at the 5 foot level, no effluent has been discharged since sewage first began entering the lagoon in 1957.

Based on a population of 200, the loading for this lagoon is 425 people/acre. Observations on the number of sump pump discharges indicate a daily discharge of 2,200 gpd. The detention period at the 5 foot level is one year. Percolation and evaporation maintain the level at approximately 2.5 feet.

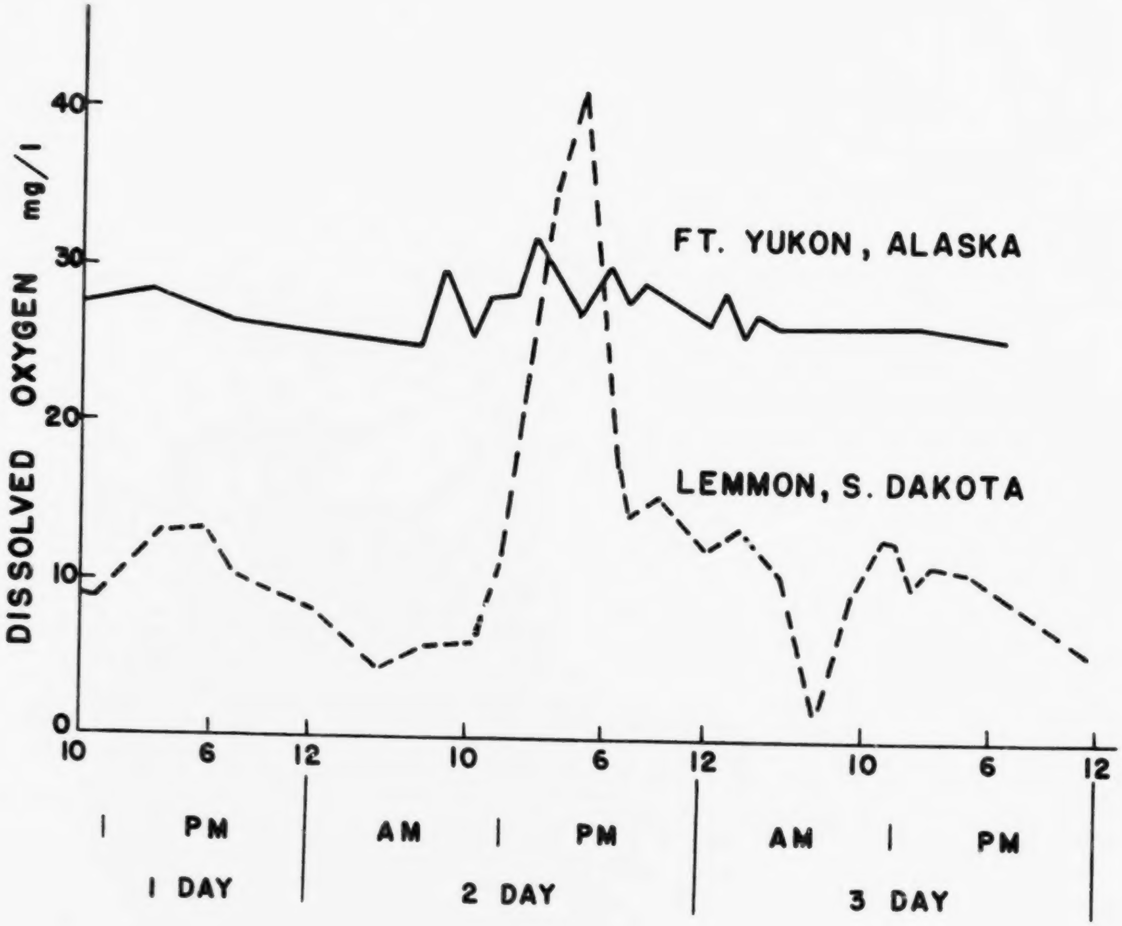
Severe winter temperatures of -60°F have not affected the flow of liquid in the sewer line. The reason for this is twofold: initial pumping temperature and intermittent pumping. The sewage has an initial temperature of 60°F when it leaves the sump in the school house and is pumped intermittently to the lagoon.

During the winter 1957-1958, ice thickness varied according to the distance from the center inlet. Directly above the inlet there was no ice, whereas near the shore, the lagoon was frozen solid. The following spring as the ice melted and began to rise, it carried with it the horizontal inlet pipe and broke off a section near the shore. Consequently, the lagoon froze solid the following winter except for an area 25 feet in radius around the shore inlet.

During the spring transitional period of 1959, samples obtained for plankton identification indicated that the sewage organic matter in the top 6 inches of the lagoon was stabilized in one month after the ice left the pond (1). An analyses of dissolved oxygen content in the spring of 1960 tended to substantiate this belief. Hourly samples collected over a 24-hour period showed the lagoon in a continuous state of dissolved oxygen saturation. Figure 11 is a comparison of these results with the diurnal fluctuations reported by Towne etal (2) in their North Dakota studies. Since an abundance of oxygen is available consistently instead of intermittently, it would be expected that

---

*Sr. Asst. Sanitary Engineer, Arctic Health Research Center, Public Health Service, Anchorage, Alaska.



DIURNAL FLUCTUATIONS IN DISSOLVED OXYGEN AT DIFFERENT LATITUDES

FIGURE 11

an arctic lagoon could support a larger bacterial population, resulting in a shorter period of stabilization for any given amount of B.O.D.

The stabilization lagoon at Ft. Yukon is unique in that it is loaded only during the winter months, at which time an adequate ice cover prevents the spreading of obnoxious odors. Following the disappearance of ice in the spring, it appears that complete stabilization is attained within one month. The biological mechanisms responsible for such an accelerated reduction of wastes is contingent upon the long daylight hours which provide the necessary solar radiation for photosynthetic activity in the algae.

Because of the vast land area in arctic and subarctic regions, the use of lagoons in Alaska presents an inexpensive means for treating domestic sewage. It has been shown that successful lagoon operations can be maintained even in such adverse climatic conditions as might be found in Ft. Yukon, Alaska.

REFERENCES

(1) Anderegg, J. A., Walters, C.F. Hilliard, D., Meyers, H.F., "Eskimo Algae Make Lagoons Work at the Arctic Circle", Wastes Engineering, 31, 6, 324 (June 1960).

(2) Towne, W.W., Bartsch, A.F., Davis, W. H., "Raw Stabilization Ponds in the Dakotas", Sewage and Industrial Wastes, 29, 4, 377 (April 1957).

IMPROMPTU REMARKS MADE

by

Joe Williamson, Jr.

This meeting has resulted in being the most important three day session I have ever attended in my 31 years in sanitary engineering. To you who are present I say you are lucky, because you are seeing history made here.

In school I studied Babbitt, edition of 1928. It takes a good three years to compile the data, write, edit, print and market a textbook on such technical subjects as "Sewerage and Sewage Treatment". It might be said, therefore, that Babbitt, edition of 1928, truly presented practices in the field in the mid-twenties. It has often occurred to me that, in basic 1960 sewage treatment plant design I could refer to said edition of Babbitt and design a modern plant. In that book were described trickling filters with rotary distributors; activated sludge; chemical precipitation; separate, covered, mechanized digesters with gas collection for heating; centrifuges for drying sludge (now experiencing, at long last, a new awakening); acidulation or acidification of sludge; sludge vacuum filters; acid precipitation; electrolysis; disinfection; etc., etc.

May I digress to say that in 1925 trickling filters were new and sanitary engineers were not quite "sure". In the beginning many engineers were violently opposed to filters. To quote Babbitt: "In the summer the filters sometimes give off offensive odors that can be noticed at a distance of half a mile, and flying insects may breed in the filter in sufficient quantities to become a nuisance if preventive steps are not taken". Even today it must be admitted that the "hands and knees" method detecting odors from conventional plants is far from being necessary, but always is with well designed and well maintained oxidation ponds.

The point I am making is that, for the best part of 35 years, there has been no major "break through" or real, practical revolutionary advancement in the art of sewage treatment as has been the case in practically every other field of modern endeavor. Would you not split your sides laughing at the sight of a 35 year old automobile creeping down the street? Yet, we are designing economically prohibitive treatment plants the basic ideas for which were all in practical application thirty-five or more years ago. This is a horrible condemnation of our profession.

At this meeting I do believe we are taking a good look at the first real "break through" unless one other very recent advancement could fall in that category. I refer to vacuum filtration of all raw sludges, primary and secondary, to eliminate the major headaches and the major operation expense in any plant; ie, conventional sludge digesters and sludge drying.

In the past I have heard many discussions on the subject "why has the art of sewage treatment been so retarded"? I have even myself been a party to the thought that most of the lack of progress may be due to some public health officials insisting on seeing anything tried in some other state fifteen years prior to approval in their states. After this meeting I will never again subscribe to such thoughts. I say this because consulting engineers, writers of our textbooks and our long-haired professional aristocracy who influence our thinking have all been asleep on the subject of oxidation ponds for stabilization of sewage. It has consistently been the public health officials in this country (down at the grass-roots level, where they know the importance of "cost") who have carried the torch in insisting on recognition and acceptance of waste stabilization lagoons.

Back in 1942, and I repeat, in 1942, (eighteen years ago) one public health official had then been crying from the house tops for some years and no one listened. In

Preceding page blank

1942 C. G. Gillespie, Chief, Bureau of Sanitary Engineering, California State Dept. of Public Health made the following statements to the Arizona Water and Sewage Association:

"That oxidation ponds are not more used can be explained by their crudity compared to neat engineering structures, the unattractive green coloration of the effluent and perhaps by the fact that too few engineers are aware of the potentialities of oxidation of organic matter. Properly laid out for size and embodying a few simple details, oxidation ponds absorb and destroy the odors of sewage, leaving nothing worse than the smell of a swamp. The effluents are permanently stable, with BOD values as good or better than those of trickling filter effluents. As a destroyer of sewage bacteria, they possess almost unbelievable efficacy. Final overflow from ponds designed for 15-day detention will show 5-50 B coli. per cc compared to something like 100,000 per cc in the original sewage. Such results continue day after day and therefore will rank with, or outrank, results from chlorination in reliability."

Obviously, prior to World War II, some few of us had considerable knowledge of the application and efficiency of oxidation ponds. Even so, we went right ahead designing temporary, emergency, conventional activated sludge and trickling filter plants for hundreds of Army and Navy cantonments utilizing tons of steel and other critical materials that should have gone into battleships. In a communistic state such neglect and lack of vision, especially in war-time, would have resulted in many of us being lined up against a wall and shot.

This meeting we are attending here is the sole result of the blood, sweat and tears of a few dedicated public health officials, such as Gillespie of California; Svore and Van Heuvelen of North Dakota; Hopkins of the P. H. S.; Ehlers of Texas; and, more recently, Brinck of Montana, our own Jack Smith of Missouri, Carl of South Dakota, Filipi of Nebraska, and Johnson of Mississippi. Out of dire necessity these men and a very few other public health officials have been forced to take over the leadership of our heretofore leaderless profession. How much longer are such men to be castigated by our reactionaries who believe no process has any merit unless it involves a three story masonry structure of huge cost upon which can be mounted a bronze plaque in their memory?

Admittedly, this is a terrible condemnation of our profession. Even so, I believe that too many of us have been keeping our mouths shut too long for the best interest of the American taxpayer. A rude awakening is in order.

CRITIQUE

By C. H. Atkins*

Although the title of this portion of the program is "Critique," the following is not intended to be so complete and thorough as to warrant such a title. Neither will it be a summary. In fact it will consist of some conclusions your speaker has drawn from the information presented at this Symposium.

The Missouri Basin Engineering Health Council has demonstrated real leadership in sponsoring this Symposium. The attendance of more than 300 persons concerned with water quality management from 32 States and 8 foreign countries indicates the tremendous interest in lagoons. This Symposium has afforded an excellent opportunity for the interchange of information on this relatively new concept in sewage treatment.

During this Symposium there have been various reports as to the time and place of the early pioneering work on the use of lagoons for sewage treatment. Much of this work was directed toward the use of lagoons in connection with conventional treatment processes. The use of lagoons for treatment of raw sewage began to get underway in this country about 1950.

This method of raw sewage treatment has been accepted by each of the 10 State Health and Water Pollution Control Agencies of the Missouri River Basin, the same agencies in other States, and by the U. S. Public Health Service. Under Public Law 660, construction grants have been made since early 1957 for 443 projects in 32 States for waste stabilization lagoon projects. Of these 432 were for raw sewage lagoons. The rate of growth in the utilization of this method of sewage treatment has been great and is accelerating.

One of the factors favoring waste stabilization lagoons is lower capital and operating costs. The information presented during this Symposium indicates that the capital cost ranges from 40 to 60 percent of the cost of conventional secondary treatment facilities. Population served, land costs, and many other factors affect this ratio. The operational costs are substantially less than for other types of treatment. These costs, however, are not zero. The lagoons must be given proper maintenance as is required of other treatment processes.

Reports from several State Health Department representatives indicate that the use of lower cost waste stabilization lagoons has accelerated the construction of sewer systems as well as treatment facilities. This is very significant from the public health standpoint. The elimination of insanitary conditions in communities and the improvement of water quality are high priority items in environmental health programs.

While this Symposium has been directed primarily to the use of lagoons for the treatment of raw sewage, there has been some discussion of other uses of lagoons. These include "polishing" of the effluent following conventional primary or secondary treatment. Another use is anaerobic lagoons for very high B. O. D. wastes such as that from meat packing plants followed by aerobic lagoons for final treatment.

Encouraging reports were made on research by industry, universities, State and Federal agencies. The results of this work thus far, however, are meager in terms of needs. Research, evaluations and demonstrations are essential in the further development and use of waste stabilization lagoons to enable realization of their full potential. High priority should be given by each of us in the support of more research by industry, universities, State and Federal Water Pollution Control Agencies and others. Pending the results of this research, we already have studies and operational experience necessary to enable a rational approach in the design and operation of lagoons for sewage treatment. The States of the Missouri River Basin have developed criteria on this basis. These criteria, which were presented at this Symposium, represent a major step in the establishment of design standards and operational practices. Variable climatic and other conditions make it necessary to provide considerable latitude in such criteria. One State indicated that rainfall and evaporation were so different within the State as to require variations in design depending upon the location within the State.

---

*Regional Engineer, U. S. Public Health Service, Region III, Charlottesville, Virginia.

Special studies and operational experience indicate that the efficiency of lagoons is comparable to secondary treatment in terms of B. O. D. reduction and that the reduction in coliforms and nutrients is greater than for conventional secondary treatment. In many instances, lagoons are used for complete retention of effluent for periods when receiving stream is critical. Holding periods up to 120 days are provided in some States during ice coverage of the streams and resultant low oxygen content. In some instances lagoons are applicable for complete containment of the sewage. They have shown unusual capability to absorb shock loads and to handle widely fluctuating waste discharges.

An example of complete containment of sewage effluent through the use of lagoons is the interim treatment works under design for the Dulles International Airport near Washington, D. C. This airport is located in the Potomac River Basin upstream from the Washington water works intakes. Public Health, aesthetic, and other considerations made it desirable to have no discharge of sewage effluent from the airport above the water intakes on the Potomac. A large interceptor is to be constructed along the river to carry sewage from the airport and other upstream areas to the Washington sewage treatment plant. Pending the completion of this interceptor, the airport sewage will be treated in lagoons. It is anticipated that there will be no overflow from the lagoons for one to two years after they are placed in operation. Subsequently, the lagoon effluent will be discharged onto the land on airport property by spray irrigation.

Satisfactory results have been reported for waste stabilization lagoons used for communities up to 15, 000 population. Some are now under construction or being planned for towns of 30, 000 to 40, 000 population plus the industrial wastes discharged to these municipal sewer systems. Likewise, this method of treatment has been demonstrated as suitable for small communities, schools, motels, resorts, slaughter houses, rendering plants, creameries, laundries and oil refineries.

The waste stabilization lagoons are not a panacea for all sewage treatment problems. The availability of land required for lagoons to serve large cities may be a limiting factor. Mosquito breeding may occur unless the lagoons are properly constructed and maintained, but no significant breeding was reported in lagoons properly designed and operated. Odors appear under certain conditions most of which may be due to improper design or operation. Certain types of industrial wastes interfere with the biological process in a manner similar to other biological treatment processes. Land values, topography, permeability of soil, high ground water table, climate and other factors should be considered in the selection and design of this type of facility.

Our explosive population and industrial growths have placed unprecedented demands on our water supply resource. Forecasts indicate that these will continue at an accelerated pace. These are factors underlying the growing public support for water pollution control. There is considerable competition for funds, and adequate treatment facilities are expensive for any community. It is a great challenge to meet these demands and needs. Waste stabilization lagoons have demonstrated successful use from the southern to the most northern boundary of the United States. From the information presented at this Symposium, it is concluded that this treatment process, when properly designed and operated, will work satisfactorily in any of our soil and climatic conditions for any size community. The determining factor, therefore, is the relative cost of construction and operation. Consequently, this method of sewage treatment should be considered along with other proven processes in making the engineering and economic analyses which should govern the selection of the most suitable type of treatment facility.

The Missouri Basin Engineering Health Council has rendered a valuable public service in providing extensive information on waste stabilization lagoons through the mechanism of this Symposium.

SELECTED REFERENCES ON WASTE STABILIZATION PONDS*

William Marcus Ingram, W. W. Towne, and
William Bliss Horning II**

The references cited here are pertinent in their relationship to the successful development of functional waste stabilization ponds or lagoons which treat domestic sewage in the United States. Readers of this bibliography should turn to additional references in the publications cited here for further information; obviously it is not possible to include all papers which can be related to the treatment of decomposable organic wastes, as domestic sewage, in a bibliography of this nature.

Allen, M. B.
1955. General Features of Algal Growth in Sewage Oxidation Ponds.
Publ. No. 13, Calif. State Water Pollution Control Board, pp. 1-47.

Allum, M. O.
1955. Lagoon Purification Performance in South Dakota. American City,
Vol. 70, No. 3, pp. 128-129.

Anderegg, J. A., Walters, C. F., Hilliard, D., and Meyers, H. F.
1960. "Eskimo" Algae Make Lagoons Work at the Arctic Circle. Wastes Engineering,
Vol. 31, No. 6, pp. 324-326.

Anon.
1946. Sewage Treatment at Military Installations.
Rept. Sub-committee on Sanitary Engineering, National Research Council,
Div. Medical Sciences, Washington, D. C.,
Chapter 10 - Oxidation Ponds, pp. 1023-1026.

Anon.
1957. Sewage Stabilization Ponds in the Dakotas.
Vols. I-II (Joint Rept., Depts. of Health of North Dakota, South Dakota and The U. S. Public Health Service)
Printed: Robt. A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

Anon.
1960. Waste Stabilization Lagoons: Design, Construction, and Operation Practices Among Missouri Basin States. (Reproduced by Dept. of Health, Education, and Welfare, U.S. Public Health Service, Region VI, Water Supply and Pollution Control Activities, 2200 Federal Office Bldg., 911 Walnut Street, Kansas City 6, Mo.)
Committee Report Approved by the Missouri Basin Engineering Health Council on January 1, 1960, pp. 1-12.

---

*To be associated with paper, "Some Observations on the Growth, Application, and Operation of Raw Sewage Stabilization Ponds," (See page 88).

**Biologist, Chief, and Biologist respectively of Field Operations Section, Technical Services Branch, Division of Water Supply and Pollution Control, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

Preceding page blank

Bartsch, A. F. and Allum, M. O.
1957. Biological Factors in Treatment of Raw Sewage in Artificial Ponds.
Limnology and Oceanography,
Vol. 2, No. 2, pp. 77-84.

Beadle, L. D. and Harmston, F. C.
1958. Mosquitoes in Sewage Stabilization Ponds in the Dakotas.
Mosquito News,
Vol. 18, No. 4, pp. 293-296.

Caldwell, D. H.
1946. Sewage Oxidation Ponds - Performance, Operation, and Design.
Sewage Works Journal,
Vol. 18, No. 3, pp. 433-458.

Davis, W. H.
1955. Sewage Lagoons in the Dakotas.
Off. Bull. N. D. Water and Sewage Wks. Conf.,
Vol. 23, pp. 5-6.

Ehlers, V. M.
1954. Oxidation Ponds - Their Application and Potentials.
Off. Bull. N. D. Water and Sewage Wks. Conf.,
Vol. 22, pp. 3-14.

Ellison, R. P. and Smith, R. L.
1954. Evaluating the Use of Sewage Lagoons.
Public Works,
Vol. 85, No. 3, pp. 89 and 142.

Fitzgerald, G. P. and Rohlich, G. A.
1958. An Evaluation of Stabilization Pond Literature.
Sewage and Industrial Wastes,
Vol. 30, No. 10, pp. 1213-1224.

Gidley, H. K.
1956. Treating Septic Tank Effluent by an Oxidation Pond.
Public Works,
Vol. 87, No. 1, pp. 81-82.

Gloyna, E. F. and Hermann, E. R.
1956. Some Design Considerations for Oxidation Ponds.
Proc. American Society of Civil Engineers,
Vol. 82, Paper 1047.

Gloyna, E. F. and Hermann, E. R.
1957. Discussion: (Algae in Waste Treatment by Oswald, Gotaas, Golueke and Kellen).
Sewage and Industrial Wastes,
Vol. 29, No. 4, pp. 455-457.

Gotaas, H. B., Oswald, W. J. and Ludwig, H. F.
1954. Photosynthetic Reclamation of Organic Wastes.
Scientific Monthly,
Vol. 79, No. 12, pp. 368-378.

Gotaas, H. B., Oswald, W. J., and Golueke, C. G.
1954. Algal-Bacterial Symbiosis in Sewage Oxidation Ponds - 5th Progress Report.
Institute of Engineering Research, Univ. of Calif.,
Bull. Ser. 44, No. 5, pp. 1-88.

Hermann, E. R. and Gloyna, E. F.
1958. Waste Stabilization Ponds - I Experimental Investigations.
Sewage and Industrial Wastes,
Vol. 30, No. 4, pp. 511-538.

Hermann, E. R., and Gloyna, E. F.
1958. Waste Stabilization Ponds - II Field Practices.
Sewage and Industrial Wastes,
Vol. 30, No. 5, pp. 646-651.

Hermann, E. R. and Gloyna, E. F.
1958. Waste Stabilization Ponds - III Formulation of Design Equations.
Sewage and Industrial Wastes,
Vol. 30, No. 8, pp. 963-975.

Hopkins, G. J.
1956. Raw Sewage Lagoons.
Water and Sewage Works,
Vol. 103, No. 8, pp. 566-570.

Howells, D. H., and Dubois, D. P.
1959. The Design and Cost of Stabilization Ponds in the Midwest.
Sewage and Industrial Wastes,
Vol. 31, No. 7, pp. 811-818.

Kabler, P. W.
1959. Removal of Pathogenic Microorganisms by Sewage Treatment Processes.
Sewage and Industrial Wastes,
Vol. 31, No. 12, pp. 1373-1382.

Ludwig, H. F. and Oswald, W. J., et al.
1951. Algae Symbiosis in Oxidation Ponds - I. Growth Characteristics of Euglena gracilis Cultured in Sewage.
Sewage and Industrial Wastes,
Vol. 23, No. 11, pp. 1337-1355.

Ludwig, H. F. and Oswald, W. J.
1952. Role of Algae in Sewage Oxidation Ponds.
(Symposium on the Role of Ecology in Water Pollution Control), Scientific Monthly,
Vol. 74, No. 1, pp. 3-5.

Merz, R. C., Merrell, J. C., and Stone, R.
1957. Investigation of Primary Lagoon Treatment at Mojave, Calif.
Sewage and Industrial Wastes,
Vol. 29, No. 2, pp. 115-123.

Neel, J. K.
1955. Biological Aspects of Three North Dakota Sewage Lagoons.
Off. Bull. N. D. Water and Sewage Wks. Conf.,
Vol. 23, pp. 13-15; 22.

Neel, J. K., and Hopkins, G. J.
1956. Experimental Lagooning of Raw Sewage.
Sewage and Industrial Wastes,
Vol. 28, No. 11, pp. 1326-1356.

O'Connor, D. J., and Eckenfelder, W. W., Jr.
1960. Treatment of Organic Wastes in Aerated Lagoons.
Journal Water Pollution Control Federation,
Vol. 32, No. 4, pp. 365-382.

Oswald, W. J., Gotaas, H. B., et al.
1953. Algae Symbiosis in Oxidation Ponds - II Growth Characteristics of Cholorella pyrenoidosa Cultured in Sewage.
Sewage and Industrial Wastes,
Vol. 25, No. 1, pp. 26-37.

Oswald, W. J., Gotaas, H. B., Ludwig, H. F., and Lynch, V.
1953. Algae Symbiosis in Oxidation Ponds - III Photosynthetic Oxygenation.
Sewage and Industrial Wastes,
Vol. 25, No. 6, pp. 692-705.

Oswald, W. J., and Gotaas, H. B.
1955. Photosynthesis in Sewage Treatment.
Proc. Amer. Soc. Civil Engr.,
Vol. 81, Separate No. 686, pp. 1-27.

Oswald, W. J., Gotaas, H. B., Golueke, C. G., and Kellen, W. R.
1957. Algae in Waste Treatment.
Sewage and Industrial Wastes,
Vol. 29, No. 4, pp. 437-455.

Parker, C. D.; Jones, H. L., and Taylor, W. S.
1950. Purification of Sewage in Lagoons.
Sewage and Industrial Wastes,
Vol. 22, No. 6, pp. 760-775.

Parker, C. D., Jones, H. L., and Greene, N. C.
1959. Performance of Large Sewage Lagoons at Melbourne Australia.
Sewage and Industrial Wastes,
Vol. 31, No. 2, pp. 133-152.

Pearse, L., et al.
1948. Oxidation Ponds.
Report of the Committee on Sewage Disposal Engineering Section, Amer. Pub. Health Assoc.,
Sewage Works Journal,
Vol. 20, No. 6, pp. 1021-1031.

Peterson, N. L.
1955. Sewage Treatment by Lagooning.
Off. Bull. N. D. Water and Sewage Wks. Conf.,
Vol. 23, pp. 21-22.

Sampson, E. O.
1955. A Double Duty Oxidation Pond.
Sewage and Industrial Wastes,
Vol. 27, No. 12, pp. 1410-1415.

Silva, P. C. and Papenfuss, G. F.
1953. A Systematic Study of Sewage Oxidation Ponds.
Calif. State Water Pollution Control Board,
Publ. No. 7, pp. 1-35.

Smallhorst, D. F., Walton, B. N., and Meyers, J.
1953. Design and Operation of Oxidation Ponds.
Public Works,
Vol. 84, No. 12, pp. 89-90; 111-114.

Smallhorst, D. F., Walton, B. N., and Meyers, J.
1954. Oxidation Ponds.
Texas Water and Sewage Wks. Assoc., Manual for Sewage Plant Operators, (2nd Ed.),
Chapter 13.

Steel, E. W., and Gloyna, E. F.
1955. Concentration of Radioactivity in Oxidation Ponds.
Sewage and Industrial Wastes,
Vol. 27, No. 8, pp. 941-956.

Towne, W. W.
1957. Sewage Stabilization Ponds for Suburban Housing Developments.
Journal National Home Builders Assoc.,
August, pp. 85-88.

Towne, W. W. and Davis, W. H.
1957. Sewage Treatment by Raw Sewage Stabilization Ponds.
Journal Sanitary Engineering Division,
Proc. Amer. Soc. Civil Engr.,
Paper 1337, SA-4: 1337, pp. 1-17.

Towne, W. W., Bartsch, A. F., and Davis, W. H.
1957. Raw Sewage Stabilization Ponds in the Dakotas.
Sewage and Industrial Wastes,
Vol. 29, No. 4, pp. 377-396.

Towne, W. W. and Pahren, H. R.
1959. Use of Stabilization Ponds in Treating Sewage and Industrial Wastes.
Proc. 8th Southern Municipal & Ind. Wastes Conf.,
Chapel Hill, N. C., April 1959.

Tsivoglou, E. C., Pecsox, D. A. and Valentine, R. F.
1956. Field Use of Radiotracer in a Sewage Oxidation Pond Flow Study.
Sewage and Industrial Wastes,
Vol. 28, No. 10, pp. 1211-1218.

Van Heuvelen, W.
1952. Sewage Disposal by the Lagoon Method.
Off. Bull. N. D. Water and Sewage Wks. Conf.,
Vol. 22, No. 4, pp. 24-26.

Van Heuvelen, W., and Svore, J. H.
1954. Sewage Lagoons in North Dakota.
Sewage and Industrial Wastes,
Vol. 26, No. 6, pp. 771-776.

Wennstrom, M.
1949. Biological Purification of Settled Sewage in Shallow Ponds.
Proc. United National Scientific Conf. on Conservation and Utilization of Resources, Aug. 17-Sept. 6, 1949,
Lake Success, N. Y., pp. 124-127.

Wilson, J. N., McDermott, J. H., and Livingston, A., III
1960. Performance of a Sewage Stabilization Pond in a Maritime Climate: 1957-1958.
Proc. 15th Purdue Ind. Wastes Conf.,
May 1960, (In Press).

☆U. S. GOVERNMENT PRINTING OFFICE : 1962 O - 624236